Effect of Waste Ceramic Dust (WCD) on Index and Engineering Properties of Shrink-Swell Soils

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Abstract
Recent years have witnessed rising social concern about the problem of waste management in general, and industrial waste and waste from the construction industry in particular. This problem is becoming increasingly acute due to the growing quantity of industrial, construction and demolition waste generated. This paper presents the study on effect of waste ceramic dust (WCD) on index and Engineering properties of shrink swell soil. The shrink-swell soil collected locally from Baure area, Gombe state, North-Eastern Nigeria was mixed with waste ceramic dust from 0 to 30% at an increment of 5%. From the analysis of test results it was found that liquid limit, plastic limit, plasticity index, optimum moisture content, free swell and swelling pressure decreased with increase in WCD. It was also found that the maximum dry density, unconfined compressive strength and California bearing ratio increased with an increase in waste ceramic dust content. X-ray diffraction analysis performed on the shrink-swell soil indicates that the soil consist primarily of montmorillonite. From the economic analysis it was found that waste ceramic dust up to 30% can be used in strengthening the sub grade of flexible pavements, to save the cost of construction.

Keywords: Shrink-Swell Soil; Waste Ceramic Dust; Index and Engineering Properties; Stabilization; Swelling Pressure.

Introduction

Recent decades have seen a marked upsurge in industrial and economic growth, contributing to an improved quality of life and well-being for citizens. However, we should not lose sight of the fact that every production system creates by-products and waste products which can affect the environment. These effects may occur at any point in the product's life-cycle, whether during the initial phase of obtaining raw materials, during the transformation and production phase, during product distribution or when the end user must dispose of products which are no longer required.

As a result, recent years have witnessed rising social concern about the problem of waste management in general, and industrial waste and waste from the construction industry in particular. This problem is becoming increasingly acute due to the growing quantity of industrial, construction and demolition waste generated.

It has been estimated that about 30% of daily production in the ceramic industry goes to waste (Binici, 2007). The disposal of which creates soil, water and air pollution. Koyuncu et al.(2004) had added ceramic tile dust wastes up to 40% to study its effect on swelling pressure and swelling potential of Na –bentonite and found that swelling pressure and swelling potential decreased by 86% and 57% respectively at 40% addition of ceramic tile dust waste. From the available literature it is found that limited research has been done to study the effects of waste ceramic dust on different geotechnical properties of expansive soil. Therefore the present study has been undertaken to investigate the effect of waste ceramic dust on index properties (liquid limit, plastic limit, plasticity index), compaction properties - optimum moisture content (OMC) and maximum dry density (MDD), unconfined compressive strength (UCS), soaked California bearing ratio (CBR) and swelling pressure of a shrink- swell soil.

Shrink-swell soils occurring in arid and semi-arid climate regions of the world cause serious problems on civil engineering structures. Such soils swell when given an access to water and shrink when they dry out. In Nigeria, these soils occupy an area of about $10.4x10^4$ km^2 in the North Eastern part (Ola, 1983), and is a very common cause of foundation problems. The severity of damages done by Shrink-Swell soil has been well documented in literature worldwide (Chen, 1988; Nelson and Miller, 1992; Gourley et al., 1993). There are a number of techniques available to improve the engineering properties of Shrink-swell soil to make it suitable for construction. Soil stabilization using chemical admixtures is the oldest and most widespread method of ground improvement. Furthermore several attempts are being made to control the Shrink-swell behavior of these soils using dust/powder like waste materials with and without a binder like lime; cement etc. Quarry Dust (Sabat, 2012), marble dust (Sabat and Nanda, 2011; Baser, 2009; Palaniappan and Stalin, 2009; Swami, 2002 are some of the prominent dust/powder like waste materials which have been successfully utilized for stabilization of Shrink-swell soil.

Materials and Methods

Materials

The materials used in the experiment are Shrink-swell soil and waste ceramic dust.

Shrink-Swell Soil

The Shrink-swell soil used in this study was obtained from Baure, Yelmatu Deba Local Government Area, Gombe state, North-Eastern Nigeria. The top soil was removed to a depth of 0.5m before the soil samples were taken by disturbed sampling. X-ray diffraction analysis was performed on the clay fraction of the tested soil to identify its mineralogical composition. The X-ray diffraction indicates that the soil consist primarily of montmorillonite, which is mainly responsible for the expansive characteristics of the soil. When dry, Shrink-swell soil has distinct shrinkage cracks with a width of about 20mm and they travel deep into the ground as shown in fig 1.

Figure 1. Desiccation cracks in shrink-swell soil caused by drying.

Waste Ceramic Dust (WCD)

Ceramic products are produced from natural materials containing a high proportion of clay minerals. Following a process of dehydration and controlled firing at temperatures between 700ºC and 1000ºC, these minerals acquire the characteristic properties of fired clay.

Broken/waste ceramic tiles were obtained from construction and demolition sites within Bauchi Metropolis. These tiles were broken into small pieces by using a hammer. The smaller pieces were fed into a Los Angeles abrasion testing machine to make it further smaller.

Experimental Methods

The experimental study was carried out on Shrink-swell soil samples collected at a depth of 0.5-1.0m below ground level. The laboratory tests carried out on the natural and stabilized soils includes Atterberg limits, compaction, California bearing ratio, (CBR), unconfined compressive strength (UCS) and swell pressure. For conducting different tests, the Shrink-swell soil was mixed with the waste ceramic dust from 0 to 30% at an increment of 5%. Mixes were prepared and the above mentioned tests were conducted on these samples/mixes according to the standards of the American Society for Testing and Materials.

Compaction Characteristics

The Standard Proctor tests were conducted according to the standards of the American Society for Testing and materials on the natural soil and soil stabilized with WCD mixtures to determine its compaction characteristics, namely, the optimum moisture content (OMC) and maximum dry density (MDD). The soil was mixed with various amounts of WCD of 5%, 10%, 15%, 20%, 25% and 30% by weight of soil and standard proctor test were conducted on these mixtures.

Unconfined Compressive Strength (UCS) value of soil waste crumb Dust

UCS tests were conducted according to British standard on the Shrink-swell soil with various percentages of WCD to determine the UCS value and to evaluate the suitability of soil stabilized with WCD. The UCS tests were conducted on soil sample-waste ceramic dust mixture prepared at an OMC and MDD obtained corresponding to that particular soil- Waste ceramic dust mixture. The soil was mixed with WCD of 5%, 10%, 15%, 20%, 25% and 30% by weight of soil and UCS test were conducted on these soil- waste ceramic mixtures.

Testing of soil samples for California bearing ratio (CBR).

The soaked California bearing ratio test was conducted in accordance with British standards. Soil samples were prepared by dynamic compaction method and placed on the bottom plate of the loading device and load was applied at a strain rate of 1.25 mm/min. Penetration was measured by strain gauge. Load was recorded at the penetration of 0.0, 0.5, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0 and 12.5 mm. CBR value is expressed as a percentage of the actual load causing the penetrations of 2.5 mm or 5.0 mm to the standard loads. The greatest value calculated for penetrations at 2.5mm and 5.0mm will be recorded as the CBR.

The California bearing ratio is calculated as follows:

$$\text{California bearing ratio (C.B.R)} = \frac{pt}{ps} \times 100 \qquad \ldots \text{(i)}$$

Where,

Pt = corrected test load corresponding to the chosen penetration from the load penetration curve
Ps = standard load for the same depth of penetration

Testing of soil for Free Swell.

$10cm^3$ (V_i) of dry soil passing through No.40 ASTM sieve was poured into $100cm^3$ graduated cylinder containing water. The volume of Shrink-swell soil increases on coming in contact with water. The increased volume of settled soil in the cylinder was measured directly after 24 hours, which gives the final volume swelled volume of soil (v_f). The soil was mixed with various amounts of WCD of 5%, 10%, 15%, 20%, 25% and 30% by weight of soil and free swell test was conducted on these mixtures. The free swell (S_f) was then computed as:

$$S_f = \frac{v_f - v_i}{v_i} X\, 100 \qquad \ldots (ii)$$

where:

S_f = free swell, (%)
V_i = initial volume of dry poured soil, (cm^3)
V_f = final volume of poured soil after 24hours contact with water, (cm^3)

Results and Discussion

The results of Natural and stabilized soil are shown in table1 and 2 respectively.

Table 1. Index and Engineering properties of Natural Shrink-Swell Soil

Property	Quantity
Grain Size Analysis	
Sand, %	3.0
Silt, %	27.0
Clay, %	70.0
Specific gravity	1.9
Natural moisture content, %	35.0
Liquid limit, %	71.0
Plastic limit, %	32.0
Plasticity index, %	39.0
Linear shrinkage, %	17.0
Free swell, %	111.0
Swelling pressure kN/m^2	130.9
USCS	CH
Maximum dry density, Mg/m^3	15.6
Optimum moisture content, %	20.4

Unconfined compressive strength, KN/m^2	55.0
California Bearing Ratio, %	1.6
Colour	Greyish black
Dominant clay mineral	Montmoriloinite

Source: Field Data (2015

Table 2 Index and Engineering Properties of Stabilized Soil

WCD (%)	**LL** (%)	**PL** (%)	**PI** (%)	**FS** (%)	**SP** (kN/m^2)	**MDD** (Mg/m^3)	**OMC** (%)	**UCS** (KN/m^2)	**CBR** (%)
0	71	32	39	111	130	15.6	20.4	55	1.6
5	65	29	36	108	121	15.8	19.8	60	1.8
10	54	26	28	101	115	16.1	19.4	68	2.1
15	51	24	27	67	83	16.5	19.0	72	2.5
20	47	22	25	52	60	17.2	18.5	80	2.8
25	43	20	23	44	51	17.5	18.2	89	3.5
30	35	18	17	36	38	18.1	17.6	98	4.1

Source: Field Data (2015)

Key: ***WCD:*** *Waste Ceramic Dust*, ***LL:*** *Liquid Limit***,** ***PL:*** *Plastic Limit*, ***PI:*** *Plasticity Index*, ***FS:*** *Free Swell***,** ***SP;*** *Swell Pressure*, ***MDD;*** *Maximum Dry Density*, ***OMC:*** *Optimum Moisture Content***,** ***UCS;*** *Unconfined Compressive Strength***,** ***CBR:*** *California* Bearing Ratio

Effect of WCD on Atterberg Limits

The results of liquid limit tests on shrink- swell soil treated with different percentages of waste ceramic dust are shown in Figure 2. From the figure it can be seen that with increase in percentage of waste ceramic dust, the liquid limit of soil goes on decreasing. It decreases from 71% to 35%, when WCD was increased from 0 to 30%.

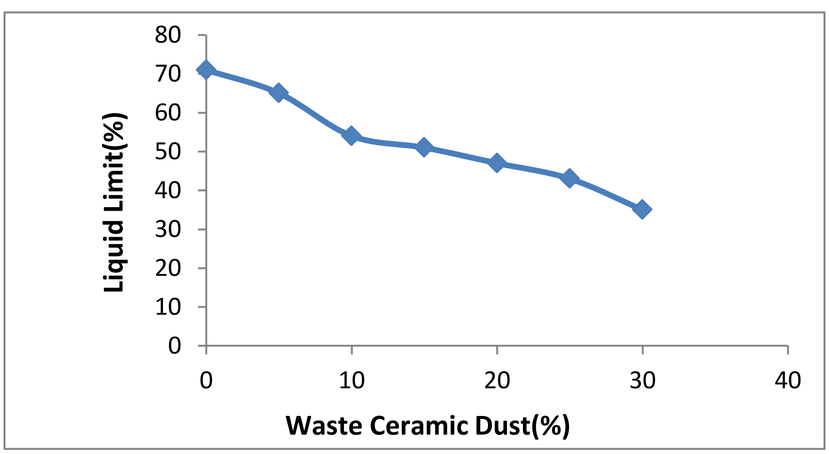

Figure 2: Variation of Liquid limit with percentage of waste ceramic dust

The results of plastic limit tests on shrink- swell soil treated with different percentages of ceramic dust are shown in Figure 3. From the figure it can be seen that with increase in percentage of WCD, the plastic limit of soil goes on decreasing. The plastic limit decreases from 32% to18% when WCD was increased from 0 to 30%.

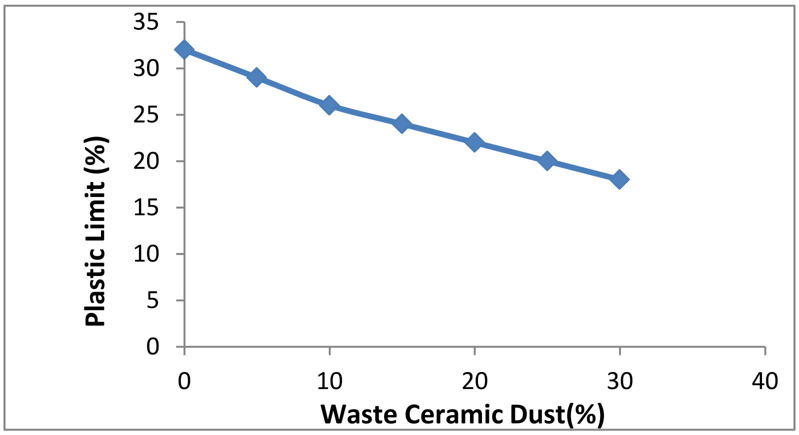

Figure 3: Variation of Plastic limit with percentage of waste ceramic dust

The variation of plasticity index with percentage of WCD is shown in Figure 4. From the figure it can be observed that the plasticity index goes on decreasing with addition of WCD. The plasticity index decreases from 39% to 17% when WCD was increased from 0 to30%.

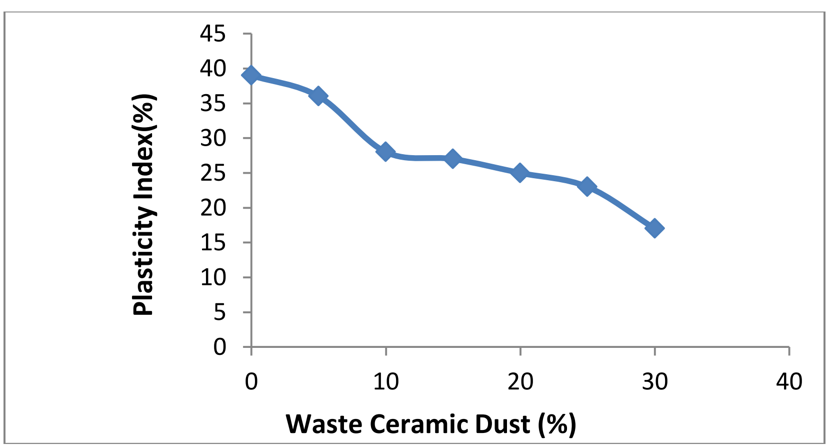

Figure 4: Variation of Plasticity index with percentage of waste ceramic dust

Effect of WCD on Compaction Characteristics

The results of standard Proctor tests on shrink- swell soil treated with different percentages of WCD are shown in Figures 5 and 6. Figure 5 shows the variation of MDD with percentage of WCD. With increase in percentage of WCD, the MDD of soil goes on increasing. The MDD increases from 15.6 kN/m^3 to18.1 kN/m^3 when WCD were increased from 0 to30%. The reason of such behavior is due to replacement of WCD particles having high specific gravity (2.82) with soil particles having low specific gravity (1.9).

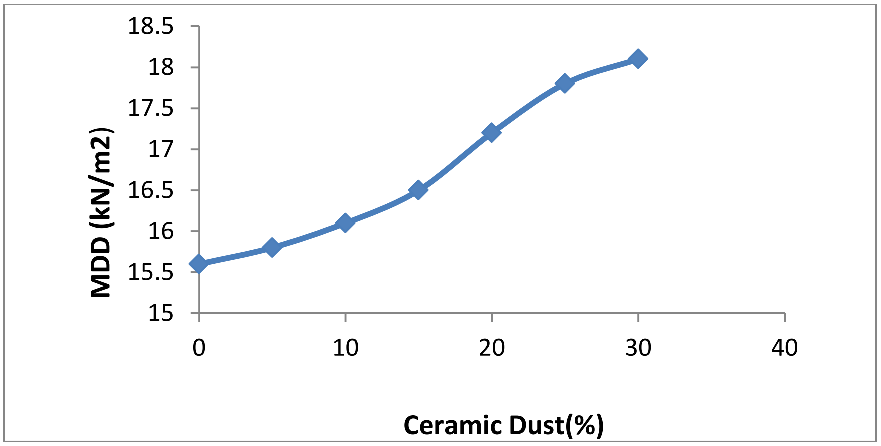

Figure 5: Variation of MDD with percentage of waste ceramic dust

Figure 6 shows the variation of OMC with percentage of WCD. With increase in percentage of WCD, the OMC of soil goes on decreasing. The OMC decreases from20.4% to 17.6% when WCD was increased from 0 to 30%. The reason of such behavior is, due to replacement of ceramic dust particles with soil particles which decrease the attraction for water molecules and hence a decrease in OMC.

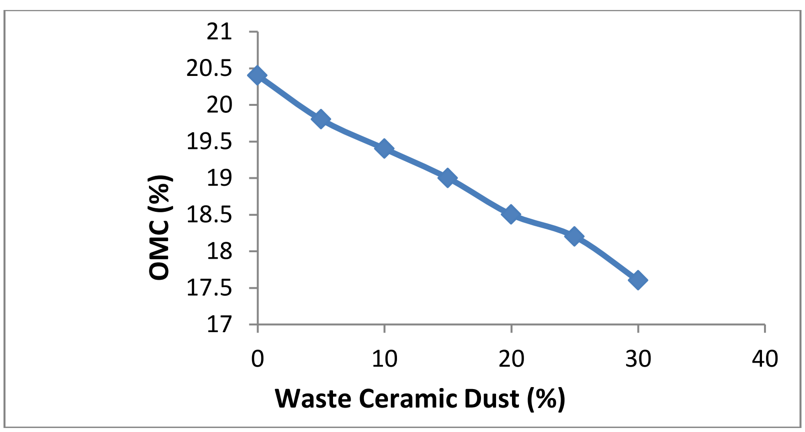

Figure 6: Variation of OMC with percentage of waste ceramic dust

The results of soaked CBR tests on shrink- swell soil treated with different percentages of WCD are shown in Figure 7. From the figure it can be seen that with increase in percentage of WCD, the soaked CBR of soil goes on increasing. The soaked CBR increases from 1.6% to 4% when WCD was increased from 0 to 30%. There is 150% increase in soaked CBR of soil at this percentage of WCD as compared to untreated soil. As MDD increases with increase in the percentage of WCD, it results in increase in both the UCS and soaked CBR values of the soil.

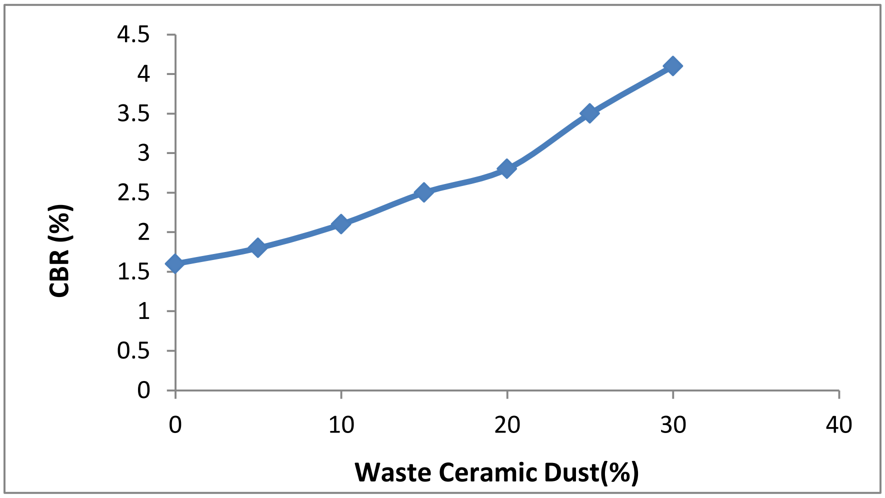

Figure 7: Variation of Soaked CBR with percentage of waste ceramic dust

The results of UCS tests on shrink- swell soil treated with different percentages of WCD are shown in Figure 8. From the figure it can be seen that with increase in percentage of WCD, the UCS of soil goes on increasing. The UCS increases from 55 kN/m^2 to 98 kN/m^2 when WCD was increased from 0 to 30%.

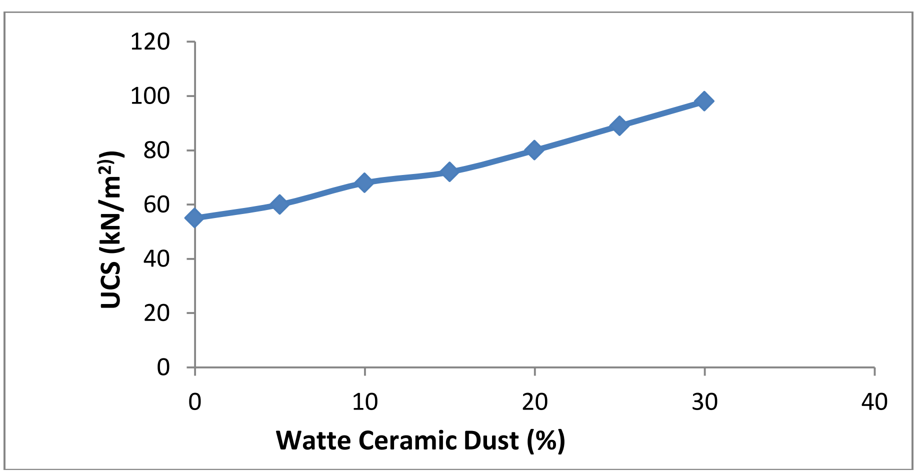

Figure 8: Variation of UCS with percentage of waste ceramic dust

The results of swelling pressure tests on Shrink-swell soil treated with different percentages of WCD are shown in Figure 9. From the figure it was observed that with increase in percentage of WCD, the swelling pressure of soil goes on decreasing. The swelling pressure decreases from 130kN/m^2 to 38 kN/m^2 when WCD was increased from 0 to 30%. There is 92% decrease in swelling pressure of the soil at this percentage of WCD as compared to the untreated soil .This happens due to decrease in clay content of the shrink-swell soil by replacement of ceramic dust, which is non-expansive in nature. As the attraction for water molecules decreases, the swelling nature of the soil decreases which result in decrease in the swell pressure.

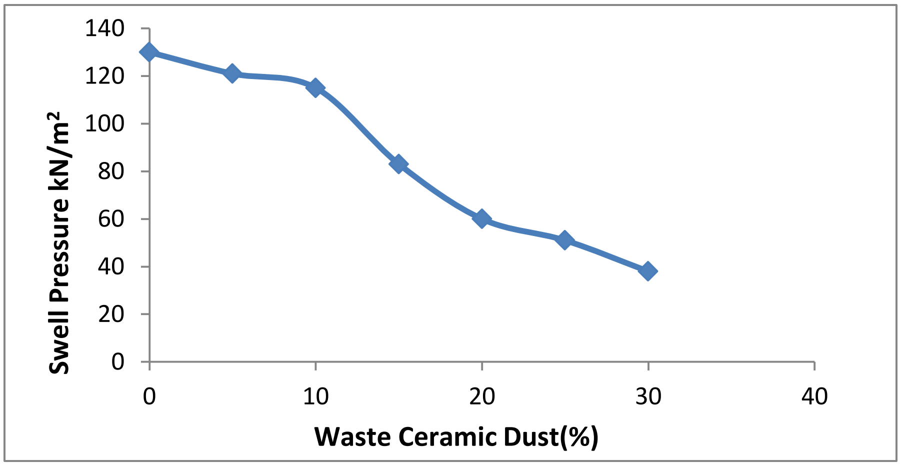

Figure 9: Variation of Swelling Pressure with percentage of waste ceramic dust

The results of free swell characteristics of the investigated soil is shown in figure10.From the figure it can be seen that the percentage of free swell goes on decreasing with addition of ceramic dust. The free swell decreases from 111% to 36% when ceramic dust was increased from 0 to30%.

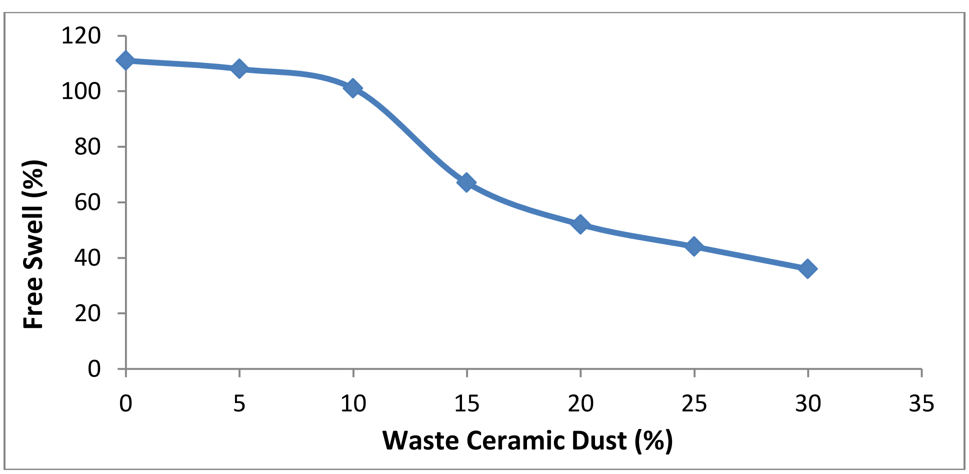

Figure 10: Variation of free swell with percentage of waste ceramic dust

Conclusion/Recommendation

Based on the observations and discussions from the study it can be concluded that waste ceramic dust is suitable for improving the index and engineering properties of Shrink-Swell Soils. The index properties (liquid limit, plastic limit and plasticity index) of the shrink –swell soil go on decreasing irrespective of the percentage of addition of ceramic dust. The MDD goes on increasing and OMC goes on decreasing with increase in percentage of addition of ceramic dust. The soaked CBR goes on increasing with increase in percentage of addition of ceramic dust. There is 150% increase in soaked CBR value as compared to untreated soil, when 30% ceramic dust was added. The Free swell and swelling pressure of the soil also decreased with increase in waste ceramic dust.

From the construction waste management and economic point of view, it is recommended that up to 30% of waste ceramic dust can be utilized for strengthening the sub grade of flexible pavement with a substantial save in cost of construction.

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