REVIEW ON THE EFFECT OF WASTE CERAMIC DUST ON THE GEOTECHNICAL PROPERTIES OF EXPANSIVE SOILS

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Abstract – *The expansive soils alternatively swells and shrinks depending upon the presence of moisture in it. This behavior causes the volume change of the soil and it results the cracking and failure of structures built on that soil. To improve the geotechnical properties of this expansive soil so as to make them suitable for construction purposes, various methods are in available. This paper reviews the results of the experimental programme which is already carried out by stabilizing the expansive soil using ceramic dust made from locally available waste ceramic tiles. Also it reviews the economic feasibility of utilizing the ceramic dust for improving the properties of expansive soil used for construction.*

Key Words: **Atterberg limits, Standard Proctor compaction tests, Unconfined Compressive Strength tests, Soaked CBR tests, Direct Shear tests, Swelling pressure tests, Cost of pavement.**

1. INTRODUCTION

Expansive soils are the soils which swell significantly when come in contact with water and shrink when the water squeezes out [1]. They are also referred as swelling soils, are those soils which have tendency to increase in the volume whenever the moisture content (i.e. water content) in it is increased. Because of this alternate swell - shrink behavior of the soil, the change in soil volume will occur and it can cause shifting and cracking in different civil engineering structures founded on them. Foundation with swelling soil will heave and can cause lifting of a building or structure laid on it whenever the moisture content rises [2]. This can ultimately lead to the failure of foundation and structure laid on it [1].

Ceramic dust is produced as waste from ceramic bricks, roof and floor tiles and stoneware waste industries. The Indian ceramics industry, which is comprised of wall and floor tiles, sanitary ware, bricks and roof tiles, refractory materials and ceramic materials for domestic and others use is producing approximately 15 to 30 MT per annum waste. Out of total waste, 30% goes as waste in and dumped the powder in open space [2]. The disposal of this ceramic waste creates soil, water and air pollution.

There are a number of techniques available to improve the engineering properties of expansive soil to make it suitable for construction. Stabilization using dust/powder like waste materials with and without a binder like lime, cement etc. is one of them. Ceramic dust, Quarry dust, Marble dust, Baryte powder, Pyroclastic dust, Brick powder are some of the prominent dust/powder like waste materials which have been successfully utilized for stabilization of expansive soil[4]. Stabilization with waste ceramic dust is an effective and economical technique to improve the geotechnical properties of expansive soil. Also ceramic dust can be utilized for strengthening the subgrade of flexible pavement with a substantial save in cost of construction.

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.

2. EXPERIMENTAL PROGRAMME

2.1 Materials used

Materials used in the experiments are Expansive soil and Ceramic dust.

a. **Expansive soil:-**

A local expansive soil from Bhubaneswar (The capital of Odisha) was used in the investigation. The geotechnical properties of the expansive soil are given below.

Table -1: The geotechnical properties of the expansive soil used

Sl.No.	Properties	Value
1	Grain size Analysis Sand size Silt size Clay size	 18% 26% 56%
2	Specific Gravity	2.68
3	Atterberg's limits Liquid limit Plastic limit Plasticity Index	 62% 30% 32%

4	Compaction Characteristics Optimum Moisture Content Maximum Dry Density	 20.4% 15.6 kN/m^3
5	Unconfined Compressive Strength	55 kN/m^2
6	Soaked CBR	1.6%
7	Shear strength parameters Cohesion Angle of internal friction	 18 kN/m^2 13°
8	Swelling pressure	130 /m^2

b. Ceramic Dust:-

Locally collected waste ceramic tiles from the industries around the Bhubaneswar are used in the experiment. The geotechnical properties of the ceramic dust used in the experimental programme are given below.

Table -2: The geotechnical properties of the ceramic dust used

Sl.No.	Properties	Value
1	Grain size Analysis Sand size Silt size Clay size	 48% 31% 21%
2	Specific Gravity	2.82
3	Compaction Characteristics Optimum Moisture Content Maximum Dry Density	 16.5% 21 kN/m^3
4	Shear strength parameters Cohesion Angle of internal friction	 8 kN/m^2 39°

3.2. TESTING PROCEDURE

Broken/waste ceramic tiles were collected from a local supplier. These tiles were broken into small pieces by using a hammer. The smaller pieces were fed into a Los Angeles abrasion testing machines to make it further smaller. For conducting different tests, the expansive soil was mixed with the ceramic dust from 0 to 30% at an increment of 5%. In total 7 mixes were prepared. Different tests were conducted on these samples/mixes according to relevant Indian Standard (IS) Codes[3].
The different tests conducted to study the effect of ceramic dust in the expansive soil are;

Liquid Limit tests
Plastic limit tests
Standard Proctor compaction tests
Unconfined Compressive Strength tests
Soaked CBR tests
Consolidated Undrained Direct Shear tests
Swelling pressure tests

3. ANALYSIS OF TEST RESULTS

Various lab tests are conducted as per the guidelines of Indian Standard (IS) codes and the results obtained are analysed below.

a) Liquid Limit Test-

The results of liquid limit tests on expansive soil treated with different percentage of ceramic dust are shown in Chart - 1.

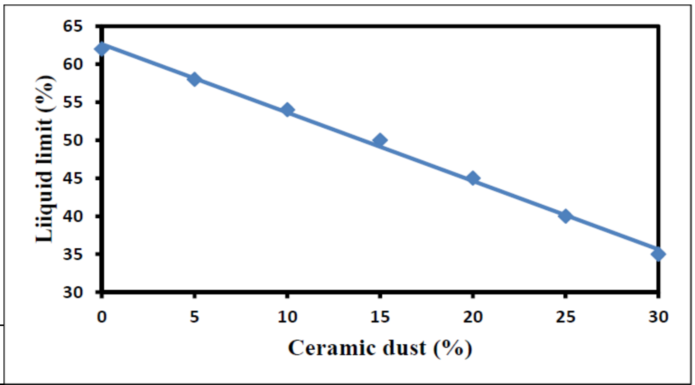

Chart -1: Variation of Liquid limit with percentage of Ceramic dust

From the chart it can be seen that with increase in percentage of ceramic dust the liquid limit of soil goes on decreasing. It decreases from 62% to 35%, when ceramic dust is increased from 0 to 30%.

b) Plastic Limit Test-

The results of plastic limit tests on expansive soil treated with different percentage of ceramic dust are shown in Chart – 2.

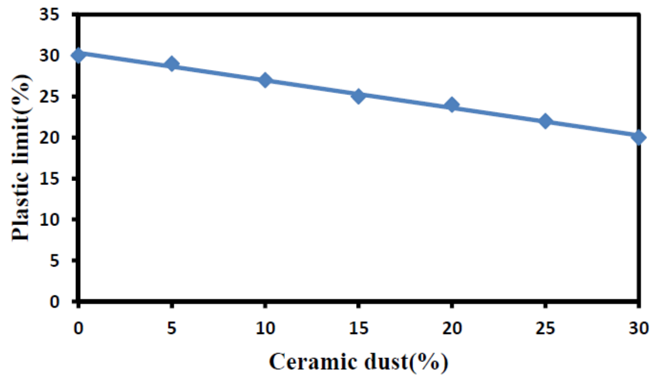

Chart -2: Variation of Plastic limit with percentage of Ceramic dust

From the chart it can be seen that with increase in percentage of ceramic dust, the plastic limit of soil goes on decreasing. The plastic limit decreases from 30% to 20% when ceramic dust is increased from 0 to 30%.

c)Plasticity Index-

Plasticity Index is the numerical difference between the liquid limit and the plastic limit of a fine grained soil. Plasticity Index of the expansive soil is calculated from the results obtained in Liquid limit and Plastic limit tests

$$PI = LL - PL$$

The variation of plasticity index with percentage of ceramic dust is shown in Chart – 3.

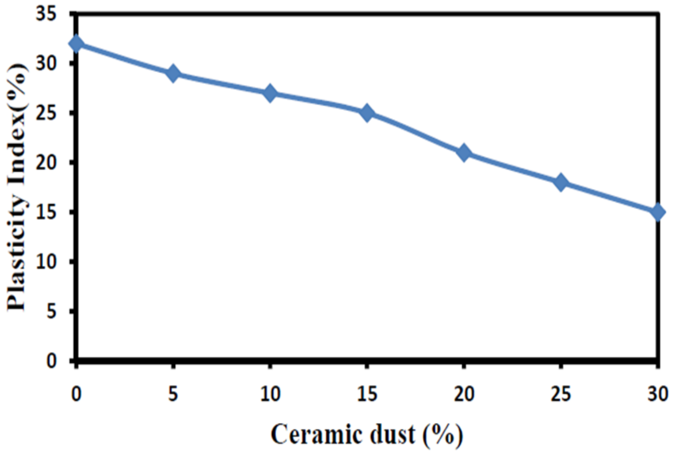

Chart -3: Variation of Plasticity index with percentage of Ceramic dust

From the figure it can be observed that the plasticity index goes on decreasing with addition of ceramic dust. The plasticity index decreases from 32% to 15% when ceramic dust is increased from 0 to 30%.

d) Standard Compaction Test-

The results of standard Proctor tests on expansive soil treated with different percentage of ceramic dust are shown in Charts – 4 and 5.

Chart-4 shows the variation Maximum Dry Density (MMD) with percentage of ceramic dust. From the chart it is clear that with increase in percentage of ceramic dust, the Maximum Dry Density of soil goes on increasing.

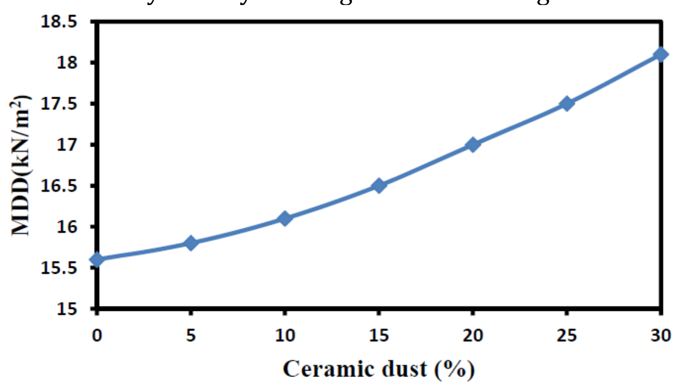

Chart -4: **Variation of MDD with percentage of Ceramic dust**

The MDD increases from 15.6 kN/m^3 to18.1 kN/m^3 when ceramic dust is increased from 0 to 30%. The reason of such behavior is due to replacement of soil particles having low specific gravity (2.68) with ceramic dust particles having high specific gravity (2.82). Also the void spaces in the soil are filled by the dust particles. So that the void ratio also decreases.

$$\gamma_d = \frac{G\gamma_w}{1 + e}$$

When the specific gravity (G) increases and the void ratio (e) decreases, the dry density of the soil increases.

Chart-5 shows the variation of Optimum Moisture Content with percentage of ceramic dust. OMC is the water content at which the dry density become its maximum value. The expansive soil has more tendency to attract water molecules into it. Because of that, the optimum moisture content of these soils are high as 20.4% in the unstabilized conditions.

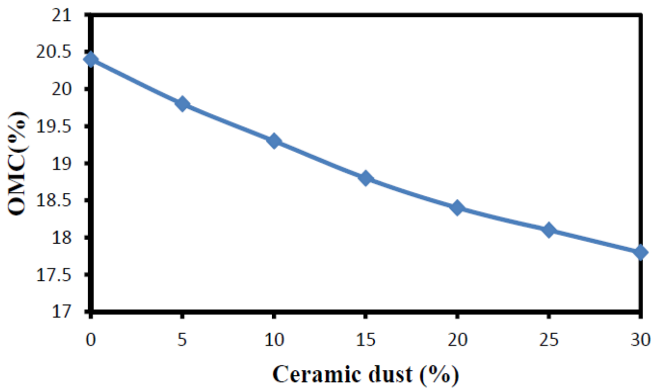

Chart -5: **Variation of OMC with percentage of Ceramic Dust**

The OMC decreases from 20.4% to 17.6% when ceramic dust is increased from 0 to 30%. The reason of such behavior is, due to replacement of soil particles with ceramic dust particles, so that the attraction for water molecules decreases hence, OMC decreases.

e) Unconfined Compressive Strength Tests –

It is a very rapid and inexpensive lab test used to determine the strength of the soil. The results of UCS tests on expansive soil treated with different percentage of ceramic dust are shown in Chart- 6.

In the unstabilised condition the unconfined compressive strength of expansive soil used in the experiment was 55 kN/m^2. From the figure it can be seen that with increase in percentage of ceramic dust, the Unconfined Compressive Strength of soil goes on increasing.

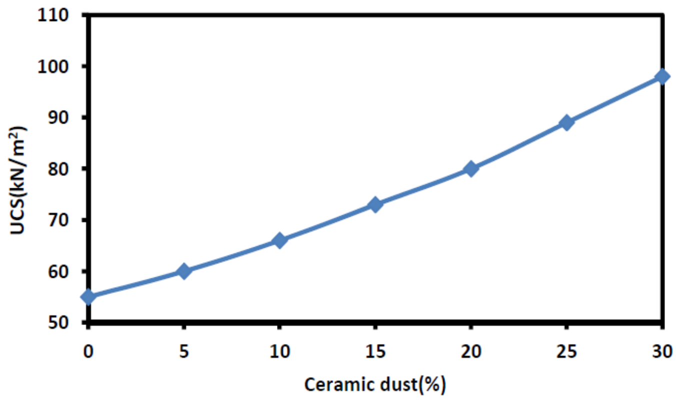

Chart- 6: Variation of UCS with percentage of Ceramic dust

From the figure it can be seen that the UCS increases from 55 kN/m^2 to 98 kN/m^2 when ceramic dust is increased from 0 to 30%.

f) Soaked California Bearing Ratio –

CBR and Unconfined compressive strength (UCS) are often used to estimate the bearing Capacity soils (Gidigasu, 1980). CBR test can be done in both soaked and unsoaked conditions of specimens. The influence of soaking is obvious in the results obtained. According to Simon et al (1973), a high reduction in CBR values after soaking indicates that the soil is very sensitive to changes in the moisture content. Hence, adequate drainage facilities are to be provided if these soils are to be used for any construction purpose to prevent loss of strength.

The results of soaked CBR tests on expansive soil treated with different percentage of ceramic dust are shown in Chart-7.

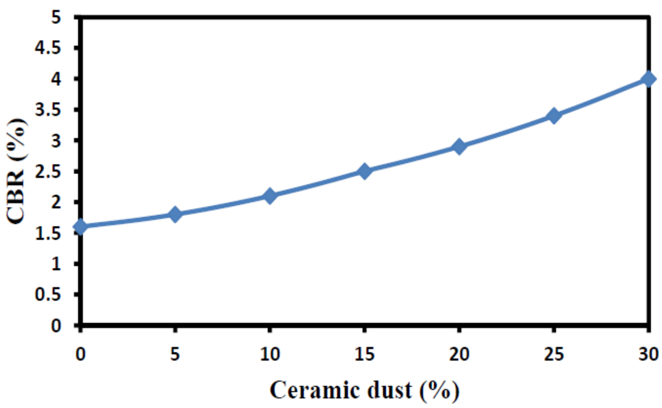

Chart- 6: Variation of Soaked CBR with percentage of Ceramic dust

From the chart it can be seen that with increase in percentage of ceramic dust, the soaked CBR of soil goes on increasing. The soaked CBR increases from 1.6% to 4% when ceramic dust is increased from 0 to 30%. There is 150% increase in soaked CBR of soil at this percentage of ceramic dust as compared to untreated soil. Also the CBR of the unstabilized soil is very sensitive to change in molding water content and that of ceramic dust stabilized expansive soil is insensitive to change in molding water content. The percentage change in CBR is very high in unstabilized soil when the sample is prepared at MDD (corresponding to OMC) but at water contents both dry and wet of optimum, where as it is negligible in case of stabilized soil.

As MDD increases with increase in the percentage of ceramic dust, it results in increase in both the UCS and soaked CBR values of the soil. The reason of such type of behavior of the stabilized soil is the reduction in clay content of soil by replacement of soil by waste ceramic dust mix. It is another advantage of using ceramic dust stabilized expansive soil in place of unstabilized soil in pavement construction other than the advantages of increased CBR.

g) Shear Tests –

Consolidated undrained direct shear tests are conducted to determine the shear strength parameters of unstabilized and stabilized expansive soils. The cohesion and Angle of internal friction are the shear strength parameters of soils. The results of shear tests are shown in Charts 7 and 8.

Chart 7 shows the variation of cohesion with varying percentage of waste ceramic dust in the expansive soil.

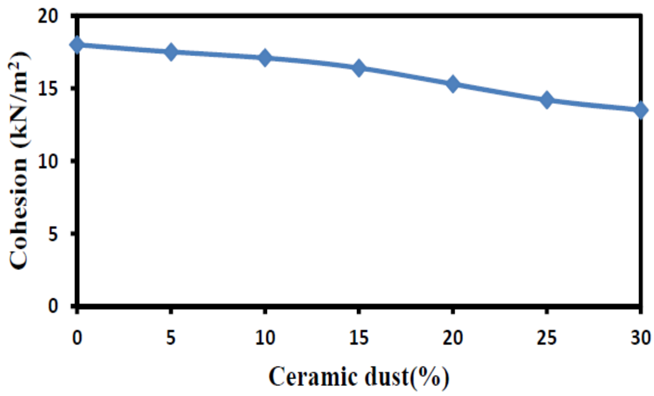

Chart -7: Variation of Cohesion with percentage of Ceramic dust

It is observed that with increase in percentage of ceramic dust, the cohesion of soil goes on decreasing. The cohesion decreases from 18 kN/m^2 to 13.5 kN/m^2 when ceramic dust is increased from 0 to 30%.

Chart- 8 shows the variation of Angle of shearing resistance with different percentage of waste ceramic dust in the expansive soil used in the investigation.

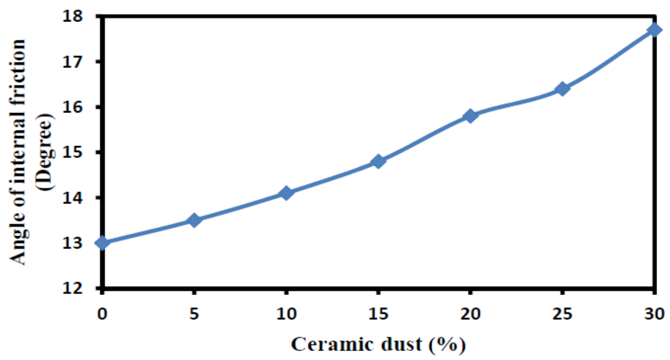

Chart -8: Variation of Angle of Internal friction with percentage of Ceramic dust

From the Chart it is observed that with increase in percentage of ceramic dust, the angle of internal friction of soil goes on increasing. The angle of internal friction increases from 13° to 17.7° when ceramic dust is increased from 0 to 30%.

The reason of such decrease in cohesion and increase in angle of internal friction of the expansive soil stabilized with waste ceramic dust is, the replacement of soil particles which have very high cohesion (18 kN/m^2) and low angle of internal friction (13°) with ceramic dust particles, having very low cohesion (8 kN/m^2) and high angle of internal friction(39°).

h) Swelling pressure tests –

Swelling pressure tests are done in the investigation to determine the swelling characteristics of the expansive soil mixed with various percentages of waste ceramic dust. The results of swelling pressure tests on expansive soil treated with different percentage of ceramic dust are shown in Chart- 9.

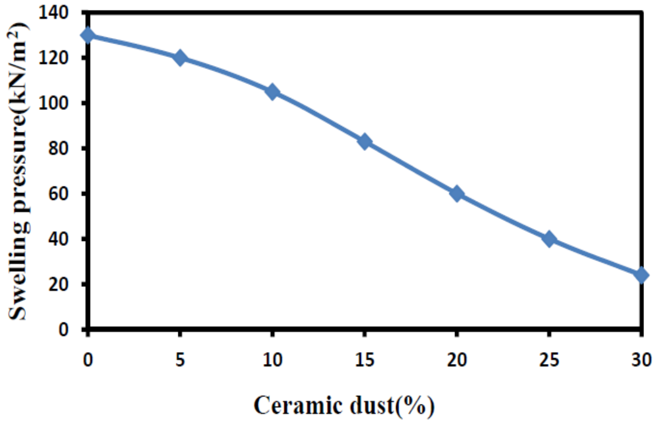

Chart -9: Variation of swelling pressure with percentage of Ceramic dust

From the chart it is observed that with increase in percentage of ceramic dust, the swelling pressure of soil goes on decreasing. The swelling pressure decreases from 130 kN/m^2 to 24 kN/m^2 when ceramic dust is increased from 0 to 30%. It means that making the highly swelling expansive soil as a low swelling material.

There is 81.5% decrease in swelling pressure of soil at this percentage of ceramic dust as compared to the untreated soil .This happens due to decrease in clay content of the expansive 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 swelling pressure.

4. ECONOMY OF STABILIZATION

To study the cost effectiveness of using waste ceramic dust mixes for stabilization of expansive soil, an economic analysis has been done. For this, a flexible pavement has been designed for cumulative traffic of 1, 5 and 10 msa (million standard axles), based on the guide lines provided by IRC: 37- 2001(Guidelines for the design of Flexible Pavements) for CBR values of both unstabilized and stabilized soil. For economic analysis, the length of the pavement has been taken as 1km and width as 3.5m.

According to IRC:37-2001, if the soaked CBR value of a subgrade is less than 2%, then the design of the pavement should be done by taking the soaked CBR value as 2% and a capping layer of 150 mm thickness with materials having minimum CBR value of 10% should be provided in addition to sub base. Hence the soaked CBR of unstabilized soil subgrade has been taken as 2% instead of 1.6% for design purpose. The soaked CBR value is 4% for the mix having proportion of soil 70% and ceramic dust 30%. Hence the soaked CBR of stabilized soil subgrade has been taken as 4% for the design purpose.

a) Pavement Thickness -

The variation of pavement thickness for both the unstabilized and stabilized subgrade, with cumulative traffic (1, 5 and 10 msa) has been shown in Chart-10.

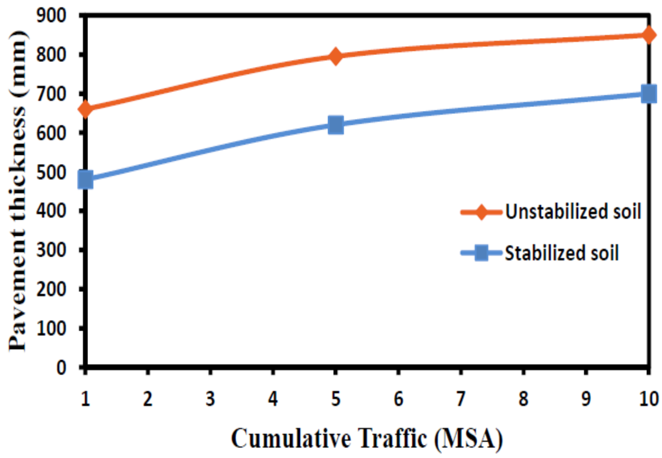

Chart- 10: Variation of Pavement thickness with Cumulative Traffic

It can be seen from this figure that the pavement thickness varies from 660 mm to 850 mm for unstabilized soil and from 480 mm to 700 mm for stabilized soil for cumulative traffic 1 - 10 msa.

b) Cost of pavement –

As per the schedule of rates -2012, Government of Odisha, India, the cost of stabilized and unstabilized pavement per m2 of pavement for cumulative traffic 1-10 msa in Indian Rupees has been shown in Chart 11. The cost includes the cost of transportation of ceramic wastes from a distance of 20 km, grinding of ceramic wastes and mixing of ceramic dust with soil.

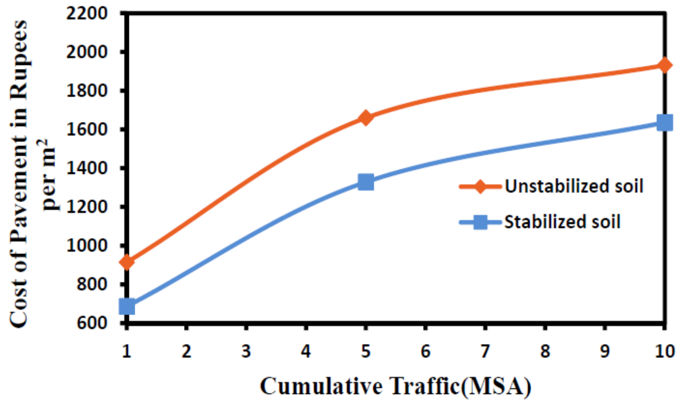

Chart- 11: Variation of cost of pavement in Rupees per m^2 with Cumulative Traffic

It can be seen from this figure, that the cost of pavement per m^2 varies from 914.5/- to 1931/- Rupees for unstabilized subgrade (which includes the cost of capping layer of 150mm thickness) and from 687.4/- to 1635.4/- Rupees for stabilized subgrade for cumulative traffic of 1 - 10 msa.

Percentage saving in cost of pavement –

Chart -12 shows the variation of percentage saving in cost of pavement per m2 for cumulative traffic of 1 to 10 msa.

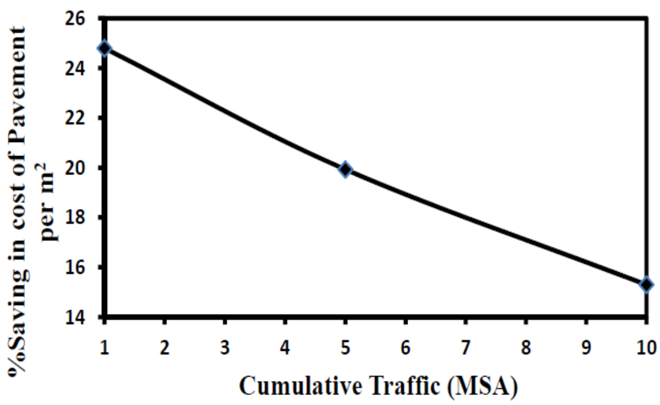

Chart – 12: Variation of Percentage savings in Cost of pavement per m^2 with Cumulative Traffic

It can be seen from this chart that the saving varies from 24.8% to 15.3% for cumulative traffic of 1 msa to 10 msa respectively.

5. CONCLUSIONS

A thorough laboratory investigation was carried out to study the improvement in geotechnical properties of an expansive soil stabilized with waste ceramic dust and economy of waste ceramic dust stabilization. Based on the observations and discussions, following conclusions are drawn from this study.

- The liquid limit, plastic limit and plasticity index go on decreasing irrespective of the percentage of addition of ceramic dust.
- The addition of 30% ceramic dust changes the soil from CH group to CL group.
- The MDD goes on increasing and OMC goes on decreasing with increase in percentage of addition of ceramic dust.
- The UCS goes on increasing 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 cohesion value goes on decreasing and angle of internal friction goes on increasing with increase in percentage of addition of ceramic dust.
- The swelling pressure goes on decreasing with addition of ceramic dust. There is 81.5% decrease in swelling pressure of soil as compared to untreated soil, when 30% ceramic dust was added.
- From the economic analysis it is found that ceramic dust up to 30% can be utilized for strengthening the subgrade of flexible pavement with a substantial save in cost of construction.
- The interaction behavior of waste ceramic dust with soils can lead to viable solution for its large scale utilization and disposal.
- Further experimental investigations are required to quantify this to use waste ceramic dust as a substitute for sand to improve the geotechnical properties of soil.

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