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EXAMINING SOIL STABILIZATION TECHNIQUES EMPLOYING CERAMIC WASTE MATERIAL: A DETAILED REVIEW

Anand Dubey, M. Tech Scholar, Department of Civil Engineering, Technocrats Institute of Technology-Excellence Bhopal, Madhya Pradesh, India Email: itsanand97@gmail.com
Dr. Ravindra Gautam, Professor, Department of Civil Engineering, Technocrats Institute of Technology-Excellence Bhopal, Madhya Pradesh, India
Pramod Kumar Professor, Department of Civil Engineering, Technocrats Institute of Technology, Bhopal, Madhya Pradesh, India
Dr. Manish Patkar Professor, Department of Civil Engineering, Technocrats Institute of Technology-Excellence Bhopal, Madhya Pradesh, India

Abstract:
Soils are naturally occurring materials that have a wide range of application in construction. In order to be deemed as acceptable for a construction activity, a soil is tested for various properties such as strength, texture, workability, permeability and plasticity. When soil does not possess the required characteristics in its natural condition, certain chemicals are mixed with soil in order to enhance or modify its properties. These chemicals are called admixtures. Soil stabilization is modification of soils with or without admixtures, to increase their load-carrying capacity and resistance to physical and chemical stress. Different types of admixtures are mixed with soil in order to modify different engineering properties. The choice of admixture and method of stabilization depends on properties of soil and type of construction.
There is a need to look towards the possible utilization of different industrial waste materials in soil stabilization. Using ceramic waste in soil stabilization is one such method which can utilize waste material to improve the properties of soil.

Key Words:
Soil, admixture, stabilization, ceramic waste, strength.

Introduction:
Soil stabilization is modification of soils, to increase their load-carrying capacity, and other strength criteria. soil stabilization in pavement design and construction is of high importance, because it can offer better soil gradation, reduce plasticity index or swelling potential, and increase the durability and strength. It also leads to reduction in thickness of pavement layer for same strength criteria as compared to Unstabilized Soil Base or sub-base course.
In India 200 MT of non- hazardous inorganic solid waste and 14.5 MT of solid waste from construction and demolition waste are being generated. India is the third-largest manufacturer of tiles in the world, accounting to 6.2% of the world production.
India generates about a 100 million metric tons of Sanitary ceramic waste (SCW) per year, majority of which ends up in landfills as waste material, thereby causing harm to environment. In various parts of India, exhaustion of coarse aggregate is happening, hence to preserve natural coarse aggregate for future needs, crushed sanitary ceramic aggregate can be used to produce a new type of soil stabilization without affecting strength.

Literature Review: The amount of research work done so far on the topic is relatively miniscule. Excerpts of the findings of past researches are discussed here in this section.
Correia et al. [2005] studied the durability factor of concrete made by partial replacement of ceramic wastes and found that the mechanical properties were proper however due to high water absorption of ceramic wastes, deleterious salts may also penetrate easily into the concrete.

Abdullah et al. [2006] indicated the strength of concrete with ceramic waste as coarse aggregate and found that the aggregate made from ceramic waste satisfies the aggregate requirement of concrete in terms of specific gravity and water absorption while compressive strength was found to be fringe to conventional concrete.

Torgal and Jalali [2010] & Torgal and Jalali [2011] examined the possibility of using ceramic wastes in concrete and their results shows that concrete mixes with ceramic aggregates have better results than the conventional concrete mixtures relating to compressive strength, capillary water absorption, oxygen permeability and chlorine diffusion thus leading to more robust concrete structures.

A.K. Sabat [2012] had stabilized expansive soil mixed with waste ceramic dust. The locally available clayey soil was mixed with ceramic dust from 0 to 30% with an increment of 5%. From the results of tests, it was found that liquid limit decreases from 62% to 35%, plastic limit decreases from 30 to 20%, Plasticity Index decreases from 32 to 15%. The compaction characteristics were also improved. Maximum dry density increased from 15.6 KN/m3 to 18.1 KN/m3, Optimum Moisture Content decreased from 20.4% to 17.6%. The Unconfined Compressive Strength increased from 55 KN/m2 to 98kN/m2. The soaked CBR value increased from 1.6% to 4%. There was 150% increase in soaked CBR value. The cohesion reduced from 18 KN/m2 to 13.5 KN/m2. When ceramic dust increases from 0 to 30% the angle of internal friction increased from 13° to 17.7°. The swelling pressure decreases from 130 KN/m^2 to 24 KN/m^2 when ceramic dust increases from 0 to 30%. It was found that ceramic dust up to 30% can strengthen the sub grade of flexible pavement with a reduction in cost of construction.

Raval et al. [2013] described the use of ceramic waste powder as partial replacement of cement and found that the use of ceramic brickwork debris as active addition endows cement with constructive characteristics as major mechanical strength and the economic benefit.

Ameta and Wayal (2013) had stabilized the expansive soil using ceramic tile waste. From the test results, it was concluded that on increment of particle size of admixture, the C.B.R. value of the mix composition increases. Also, as the quantity or percentage of admixture increases, the C.B.R. value of the mix composition increases. Increase in CBR values was more at unsoaked condition as compared to soaked condition. Angle of internal friction varies with increase in size of ceramic tiles waste particles in mix composition. However, if the size of ceramic tiles waste was kept constant, the angle of internal friction increased with increase in percentage or quantity of ceramic tiles waste.

Babita Singh and Ravi Kumar (2014) created a composite mix of the local clay with fly ash, sand, tile waste and jute fibers. The mix in proportion [clay : sand : fly ash : tile waste : jute fiber] = [63:27:10:9:0.5] was selected as the most appropriate and optimum mix proportion. The maximum dry density (MDD) of this mix was seen to decrease as the content of fly ash increased whereas optimum moisture content (OMC) increased as fly ash content increased. When tile waste was added to clay-sand-fly ash mix, the maximum dry density initially increased corresponding to a certain percentage of tile waste and then decreased. When jute fibers were added in this clay-sand-fly ash-tile waste mix, MDD increased slightly and then decreased when jute fiber content was further increased. Optimum moisture content was mostly unaffected by addition of jute fibers. A considerable improvement was seen in Soaked and unsoaked CBR values for the optimum mixes as compared to that of locally available clayey soil. A significant strain absorption capacity was seen for this final composite mix. No Considerable difference was observed in the final strength of mix as compared to that of Clay. The final optimum mix obtained was a much more improved construction material and when used in the construction of flexible pavement, imparts significant cost saving.

T. Geeta Rani, Ch. Shivanarayana (2014) had evaluated the effect of tile waste on clayey soil. The clayey soil available locally was blended with tile waste from 0 to 30% at an increment of 10%. The liquid limit and plastic limit were decreased irrespective of the percentage of addition of tile waste. The MDD attained at 20% tile waste and OMC was decreasing with increase in percentage of tile waste. The value of soaked CBR was increased when percentage of addition of tile waste was increased. The CBR value has increased by 105% as compared to untreated soil, when 20% tile waste was mixed. The swelling pressure of soil reduced by 48% as compared to untreated soil, when 20% tile waste was added. From the above analysis it was found that tile waste up to 20% can be utilized for strengthening the clayey soil sub grade of flexible pavement with considerable save in cost of construction.

Raghudeep and Prasad (2015) had mixed the available clayey soil with vitrified polish waste (VPW) up to 10% for flexible pavement construction. At 10% mix proportion of VPW, Liquid limit and Plasticity index of the soil saw a decrease of 17.29% and 42.77%, respectively. The maximum dry density increased by 13.61% and differential free swell reduced by 27.93% when 10% VPW added to the soil. Soil classification changed from the CI to CL. CBR value increases from 2.1% to 7.07%. Soaked and Unsoaked CBR values increased 3 to 4 times when 10% of VPW added to the soil compared to original clayey soil.

Daniyal and Ahmad [2015] used the crushed waste ceramic tiles and investigated the effect of it as a replacement for natural coarse aggregates and found that the compressive and flexural strength of best performing concrete was found to be 5.43% and 32.2% higher than reference concrete respectively at 30% replacement level.

Onyelowe et al (2018) chose 4 soil samples of laterite soil at 1.5m depth from surface, that were to be used as soil subgrade. Each of these samples were mixed with Ceramic Waste Dust (CWD) in varied proportions, ranging from 5 to 60% in a steady increment of 5%. Upon performing the tests for engineering properties, it was determined that all 4 samples were expansive and highly plastic with plasticity index greater than 17%. The maximum dry density among 4 samples (1.85 g/cc) occurred at Natural Moisture content of 13%, CBR of 13% and OMC of 16.2%. The soils were identified as soft clay soils unsuitable to be used as subgrade in pavement. Upon treating the soils with CWD, it was noted that swelling decreased considerably with the increase in proportion of CWD. The shrinkage limit saw an increase as proportion of CWD was increased. A direct proportional relationship was seen between shrinkage limit and drying time.

Neeladharan et al (2018) attempted to stabilize clayey soil with variable percentage of marble dust and sodium silicate, used as a binder. Marble dust was taken at 5%, 10%, 15% and 20% content, and sodium silicate binder was taken at 2.5%, 5%, 7.5% and 10% content. In order to find out the index properties, Atterberg limits tests, standard proctor test, shear box test and CBR test were conducted. From the tests results, it was found that liquid limit continued to decrease up to 15% Marble dust, and 10% Sodium Silicate, and after that, it again increased. Similarly, upon increasing the percentage of Sodium silicate and marble dust, plastic limit decreases (irregularly), and on further increase, it increases slightly. Maximum dry density increased up to 15% marble dust, and 10% sodium silicate, and attained a maximum value of 2 g/cc, but dropped considerably on further increase of Sodium silicate and marble dust. Shear box test revealed that, here too, 15% marble dust, and 10% sodium silicate gave the maximum value of shear stress at failure. similar pattern was observed in CBR test, where 15% marble dust and 10% sodium silicate provided the highest CBR % value of 16.24% at 2.5mm penetration.

Onyelowe et al. (2019) investigated the behavior of cemented soils that were treated with crushed ceramics waste for pavement subgrade construction. The soil samples were chosen from 4 open pit sites in Africa, and were treated with Ordinary Portland Cement. The admixtures used in the tests were added in the percentages of 10% to 120% at an incremental rate of 10% to treat the soils. In order to understand the basic engineering properties, tests were conducted for specific gravity, particle size distribution, Atterberg limits, compaction, shrinkage limits and free swell index. In order to find aluminosilicate content and gradation of soil, chemical oxide composition and particle size distribution tests were conducted. To find the stiffness of soil subgrade resilient modulus test was carried out. As per the results obtained, soil was classified using unified soil classification system. The results show that the soils are highly plastic soils, having high free swell index. Specific Gravity of soil samples ranged between 2.6 to 2.08. chemical oxide test indicated that test samples possess high amounts of aluminosilicates responsible for the pozzolanic, calcination and hydration reactions. The Optimum

Moisture content and Maximum dry density of treated soil sample did not show any direct proportionality with each other. OMC values ranged from 13.1 to 15.4, and MDD values ranged from 1.76 (g/cm3) to 1.56 (g/cm3). The CBR values also showed considerable variation ranging from 13% to 7%. Out of 4 samples, three showed an improvement index of about 21%, while 4^{th} sample showed an improvement index of 25%. The higher improvement index recorded with 4^{th} soil sample is due to its natural higher resilient modulus as obtained by tests.
Deboucha et al (2020) investigated the effects of marble dust (MD), ceramic waste (CW), and ordinary Portland cement on the sub-base layer soil of pavement. Marble dust, ceramic waste powder and OPC were taken at different proportions. Ceramic waste powder at 5, 10, and 15%, Marble Dust at 2, 3, 4, and 5%, and OPC at 1.5, and 2% by dry weight were taken. Tests were conducted on soil sample to determine its index properties, and it was found that Soil possessed Liquid limit of 30.37%, plasticity index of 6.32% and maximum dry density of 19.4 KN/m3. Then soil sample was mixed with Marble dust, Ordinary Portland cement and Ceramic waste powder in above mentioned proportions. Samples were then mixed with water and cured for 7, 14, and 28 days. In compaction test it was seen that MDD increased when Ceramic Waste content was between 5–10%, above which, slight decrease was seen in MDD value. Marble Dust content showed an inverse relationship with OMC. Whereas, increasing the OPC content led to an increase in OMC. However, value of MDD remained almost constant at both 1.5 and 2% OPC content. MDD showed a decrease when Ceramic waste material was more than 10%. CBR values showed a direct relationship with Both OPC dosage as well as with curing time. But It (CBR) decreased when CW content was more than 10%. Although, for CW value of 5%, high CBR value was observed at 2% OPC content, as compared to 1.5 % OPC and identical CW content.
Sivabalaselvamani et al (2022) studied the engineering properties of Expansive soil mixed with Ceramic Waste Powder (CWP). The soil specimen was mixed with ceramic waste powder in varying percentages and provided with different curing periods. specimens of Expansive soils were mixed with ceramic waste powder at 5%, 10%, 15%, 20%, and 25% content. To determine the type of soil, its engineering properties were calculated, and the soil was classified as High Compressible Clay (HCC) as per Indian Standards classification. In order to gauge the performance of treated soil sample, it was tested by conducting tests on pH and Electrical Conductivity, Unconfined Compression strength, Split Tensile strength, Free swell Index, Swelling Pressure, California Bearing ratio, and Atterberg's limits. It was seen that pH of the soil increased till 20% content of CWP in the mix, but when CWP content was increased further, the pH value reduced. Optimum value of pH was 8.98 at 20% CWP in the mix. The electrical conductivity showed inverse relationship with Ceramic waste powder content. Bulk density of mix was found to be higher than bulk density of Clay. In this respect, the results obtained for CWP mix were better than soil mixed with marble dust.
Unconfined compressive strength increased initially with increase in ceramic powder content at almost all percentages of CWP and at all curing periods (0,7,14 and 28 days). However, when proportion of CWP was increased to 25%, the UCS saw a reduction for all the curing periods. The final values of UCS obtained after 28 days at 0%, 5%, 10%, 15%, 20%, and 25% CWP content were found to be 301 kPa, 520 kPa, 610 kPa, 629 kPa, 641 kPa and 623 kPa. It was found that if curing time was increased, the strength of the soil also increased, irrespective of CWP content. Higher CWP content along with increase curing period also increased tensile strength of the sample. Free Swell index saw a reduction due to increase in CWP content. CBR value increased as CWP content was increased in the mix. Both plastic limit and liquid limit decreased, as ceramic powder content was increased.
Kasehchi et al (2024) investigated the use of ceramic waste powder in soil stabilization for silty sand. A sub surface soil sample was taken and tested for Atterberg limits. Particle size analysis test was performed and soil was concluded to be silty sand (SM) as per USCS classification criteria. Proctor compaction test was conducted to determine Optimum Moisture Content and Maximum Dry Density, which were reported as 13.7% and 18.25 (kN/m^3), respectively. Liquid limit was found to be 23.5% and plastic limit was 20%, giving plasticity index of 3.5%. The soil sample and ceramic waste powder were oven dried for 3 days at 60°C. Then required amount of both materials were mixed and solution

of Sodium Hydroxide (NaOH) was added at OMC of 13.7%. Sodium Hydroxide, being highly soluble in water and hygroscopic in nature, also absorbs carbon dioxide. Since NaOH is highly alkaline, it is used as an alkaline activator in soil stabilization. NaOH was added in varying concentrations in different samples, ranging from 2M to 15M. The mixture was then turned into cylindrical samples which had 85mm height and 36mm diameter (H/D=2.36). Samples were prepared at different percentage content of CWP ranging from 0% to 24%, with an increment of 3%. A control sample was created which had Soil mixed with 5% Ordinary Portland Cement. All samples were cured at an ambient temperature of 25℃ for 7,28 and 91 days. Then Unconfined Compression test was conducted at a Uniform strain rate of 1.27mm/minute. It was observed that at 6% CWP value, test samples had same UCS as Control sample containing OPC. On further increase of CWP content, UCS value increased, gaining maximum value at 15% CWP content. On further increasing the Ceramic content, the UCS value reduced, yet it was still higher than that of Control sample containing OPC. However, it was noted that Strain-at-failure (Ɛf) for CWP content > 15% was lesser than that of CWP=15%. Effect of curing period on UCS was negligible and UCS remained almost same at all curing periods, for same CWP content. However, if the Concentration of NaOH was Increased from 2M to 10 M, the UCS value showed a steady increase, but declined when NaOH concentration reached 15M.

Conclusion:

By using solid waste material of different types in soil stabilization, we can improve the geotechnical properties of soil. For different type of soil, use of different waste material yields different results. The result also varies with different proportion of waste material used. For different proportion of waste material added in soil, different degree of improvement.

Based on the previous works of scholars discussed above, following conclusions can be drawn:

- Soil stabilization improves strength, stability and durability, while reducing Swelling potential, plasticity index.
- India generates a very large amount of Sanitary Ceramic waste, which usually ends up in landfills. This waste material can be used as admixture in soil stabilization.
- Sanitary Ceramic Waste (SCW) has the potential to increase soil properties when used in Soil Stabilization in different proportions.
- The soils which were chosen for study, were determined to be highly plastic (clayey) soils, which means that they are expansive and unsuitable for construction purposes. Therefore, they need to be modified, in order to be suitable for construction activity.
- In tests, it was found that when ceramic waste was used as coarse aggregate, it did fulfil the criteria with respect to aggregate requirement of concrete in terms of specific gravity and water absorption while compressive strength was found to be fringe to conventional concrete.
- It was noted that when ceramics were used as aggregates, gave better results than the conventional concrete mixtures with respect to compressive strength, capillary water absorption, oxygen permeability and chlorine diffusion. Therefore, use of ceramics as aggregates provides good quality of concrete.
- It can be ascertained that optimum dosage of up to 30% of ceramic dust mixed with clayey soil reduces the liquid limit, plastic limit, plasticity index, Optimum Moisture Content and Cohesion value. Whereas it increases the Maximum dry density, Unconfined Compressive strength (by nearly 80%), Soaked CBR value (by 150%), and angle of internal friction (from 13° to 17.7°).
- When ceramic waste powder was used as a partial replacement of cement, it was seen that ceramic aided cement brickwork improved economy and strength characteristics of mortar as well.
- By adding fly ash and jute fibers with ceramic waste powder, researchers found an overall improved construction material which was suitable and economically viable to be used as soil sub-grade in pavement construction, at a fixed ratio of [clay : sand : fly ash : tile waste : jute fiber] = [63:27:10:9:0.5].

- The ceramic waste powder was found to be rich in silicates, and has similar gradation as that of soil sample and results indicate that the mix sample has good binding properties, which makes it useful as an additional cementitious (binder) material.
- It was noted that when Powder of ceramic waste was used in lime-stabilized soil, it resulted in a higher increase in strength within a shorter curing period.
- The test results showed that maximum value of compressive strength at 20% ceramic waste powder was 641 kN/m². This was significantly more than the compressive strength gained from the 20% marble dust content which was found to be 630 kN/m² after curing for 28 days. Similar results in compressive strength were observed at 7 day curing period as well.
- Tensile strength of the mix was seen to be proportional to the curing period. Highest value of tensile strength was attained at 20% Ceramic waste powder content.
- It was seen that Swelling percentage decreased when percentage of ceramic powder was Increased, thereby establishing an inversely proportional relationship.
- This behavior could possibly be attributed to the fact that when sand and silt particles are present in higher amount, they tend to increase the non-expansive nature of ceramic waste powder.
- A similar Inversely proportional relationship was observed between Free Swell Index and ceramics waste powder content.
- Swelling pressure showed a decreased with an increase in ceramic powder content. This can be explained by the fact that upon increasing the ceramic content in soil, its share of Occupied surface area also increases, which in turn resulted in reduced interaction between soil particles, leading to reduced swelling pressure.
- CBR value also showed direct proportional relationship with ceramic content, and Maximum CBR value was obtained corresponding to the 15% Ceramic Content. Thereafter, CBR value reduced with further increase in Ceramic powder content. Hence, Optimum value of Ceramics Content for CBR was determined as 15%.
- Both plastic limit and liquid limit exhibited an inverse relationship with Increasing ceramic content. Consequently, Plasticity Index (which is difference of Liquid limit and plastic limit) also reduced with increasing ceramics content.
- Optimum Moisture Content and Maximum Dry Density, both increased with increase in ceramics content, which was due to a well graded mixture and release of calcium ions into pore volume of soil which further reduced the void ratio and increase MDD.
- It was determined that the ceramic powder, when mixed into the soil released Calcium, Silica and Aluminum ions, which in turn increased the rate of hydration, thereby reducing the swelling potential.
- If curing time is excessively prolonged, it leads to an increase in swelling potential and porosity.
- the pozzolanic reaction of soil mix was improved by The Ceramic Waste Dust which had high concentration of aluminosilicates, thereby improving shrinkage limit.
- Results for above-described properties were optimum when the proportion of Ceramics was between 5 and 10%, after that, the results declined, mainly due to quantity of clay surpassing the optimum.
- When marble dust was used in the tests as an admixture, it improved the MDD, mainly because it had high CaO (Calcium Oxide) content which is already a known soil stabilizer.
- Ordinary Portland Cement was also added in this sample. It increases the MDD, but reduces the optimum moisture content. This happens due to OPC fines absorbing water from the mix.
- OPC also reduced compressibility and improved the strength of the mix sample.
- With Increasing Value combination of Marble dust and OPC, it was seen that CBR value increased initially but decreased later.
- The maximum CBR values were obtained at Combinations of ,1.5% OPC+ 5% Ceramics (117.94%) and 2% OPC+5% ceramics (263.10%). However, CBR value for (2% OPC+5% ceramics) was higher than that of (1.5% OPC+ 5% Ceramics).

- Based on the above results 5–10% Ceramic Waste content was recommended to be mixed with soil sub-grade for rural roads, whereas an addition of 1.5-2% of Ordinary Portland Cement was recommended for highway soil sub-grades.
- It was observed that when marble dust was used with Sodium silicate as an admixture for stabilizing the soil, both liquid limit and plastic limit decreased till the admixture content was 15%. After that the values of liquid and plastic limits saw a gradual increase.
- Similar behavior was observed in Maximum Dry density and CBR values.
- It can be concluded that Marble dust of 15% content mixed with Sodium Silicate of 10% content would give optimum results in stabilizing an expansive soil.
- Investigation on the effect of ceramic powder combined with sodium hydroxide (NaOH) solution revealed that NaOH acted as an alkali activator. It was found that raising the value of ceramic powder content creates very suitable situations for creation of Geopolymer Gel, which in turn, increases the Unconfined Compressive Strength (UCS). Similar pattern was observed in values of strain-at-failure values.
- Based on the test results, it can be concluded that although UCS saw a reduction with an increase in the ceramic powder content, it was still higher than UCS of soil sample stabilized by OPC alone.
- This finding calls for the increased use of ceramic waste, instead of OPC as a binder in soil stabilization. This would not only help us reduce carbon emissions (through reduced use of cement), but it will also help in reusing the waste ceramics, which would have otherwise ended up in landfills.
- Proportion of sodium hydroxide solution was also varied and based upon the results, most optimum concentration of NaOH was found to be 10M.
- Based on the experimental values of UCS and strain-at-failure, 6-15% content of Ceramic waste powder, with 10M Sodium hydroxide solution is recommended as optimum for soil stabilization.

Declaration:

We, the undersigned authors of this research paper, hereby declare that this work is our original contribution and has not been previously published, nor is it currently under consideration for publication elsewhere.

We affirm that all sources used in the preparation of this paper have been properly cited and acknowledged. Any material borrowed from other works is clearly indicated and referenced according to the appropriate scholarly conventions.

Anand Dubey (Corresponding Author)
Dr. Ravindra Gautam
Pramod Kumar

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