Recent Trends in Civil Engineering & Technology
Volume 3, Issue 2, ISSN: 2249 –8753

Compaction and Subgrade Characteristics of Clay Soil Modified with Beas Sand, Fly Ash, and Waste Ceramic

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Abstract
The most concerning problem today with the thermal power plant is the disposal of fly ash. The use of fly ash as landfill causes great environmental pollution like groundwater contamination since coal contains trace levels of heavy metals. Similarly, waste ceramic too causes great environmental problem. So, there is a need to utilize these materials by exploiting their inherent properties to solve the environmental and disposable problem. This paper brings out the results of an experimental program carried out to evaluate the effectiveness of using fly ash with randomly distributed discrete waste ceramic for soil stabilization by studying the compaction and strength characteristics for use as a subgrade material. The influence of different mix proportions of clay, sand, fly ash and ceramic on compaction, drainage and CBR values has been studied. The results show that addition of fly ash increases the OMC and decreases the MDD, but increases the CBR. The designed composite may be used effectively for construction of subgrade, embankment and foundations of low-cost roads.

Keywords: *soil, foundry sand, steel chips, MDD, OMC, CBR.*

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INTRODUCTION
Clays exhibit generally undesirable engineering properties like lose strength on wetting or other physical disturbances. They can be plastic and compressible and expand when wetted and shrink when dried. Some types expand and shrink greatly upon wetting and drying – a very undesirable feature. Cohesive soils can creep over time under constant load, especially when the shear stress is approaching its shear strength, making them prone to sliding. For these reasons, clays are generally poor materials for foundations. The annual cost of damage done to engineering structures constructed on expansive soils is in billions of dollars worldwide.

Soil stabilization has been widely recommended for developing countries for the construction of various elements of the pavements. The characteristics of compacted soil, if improved, resulting from residue utilization like fly ash brings environmental and economic benefits. Fly ash is a waste by-product from thermal power plants, which uses coal as fuel. At present about 100 thermal power plants in India produce about 130 million tons of fly ash every year. Concurrent generation of fly ash in bulk qualities is a matter of serious concern not only because of the issue associated with its disposal and utilization, but also because of threat to public health and ecology. The huge quantity of fly ash being accumulated is likely to pose problem for its disposal and pollution.

A ceramic is an inorganic, nonmetallic solid prepared by the action of heat and subsequent cooling. Ceramic materials may have a crystalline or partly crystalline structure, or may be amorphous (e.g., a glass). Floor tiles, crockery, sanitary wares and many more are the ceramic products. But such materials have been used little for engineering purposes, and the overwhelming majority of them have been placed in storage or disposal sites.

Soil stabilization involving addition of fly ash and ceramics aims to improve the engineering performance of the soil. This is typically used for a soft, clayey sub-grade beneath a road that will experience repeated loading. Fly ash is used as a mineral filler to fill the voids and provide contact points between larger aggregate particles in the asphalt concrete mixes. The hydrophobic nature of fly ash gives pavements better resistance to stripping. Other environmental benefits of recycling the fly ash include reducing the demand for virgin materials that would need quarrying and substituting materials that may be energy intensive to produce.

The usage of fly ash along with sand and ceramics has not been studied in detail yet. This study has been undertaken to explore the possibility of using fly ash in combination with sand and ceramics. The engineering properties of the composite material (i.e., soil + fly ash + sand + ceramics) have been studied. The results have been discussed to bring out the possibility of using fly ash in the construction of roads.

Significant efforts have been made in recent years to use fly ash in civil engineering construction. Mathur *et al.* [1, 2] have used fly ash in embankment with the technique of reinforced earth with a view to use this waste in road work. Thaweesak Jirathanathworn [3] reported that by using fly ash mixed with small amount of lime, it is possible to improve some of the engineering properties of clayey soil including hydraulic conductivity as well as strength. Kumar and Singh [4] have suggested the use of fly ash reinforced with propylene fibers in low-volume rural roads. Shankar *et al.* [5] reported that the addition of Pond Ash (PA) resulted in reduction of maximum dry density of blend with slight increase in optimum moisture content. Further addition of ordinary portland cement resulted in improvement of strength characteristics. P. Eskioglou and N. Oikonomou [6] showed that the addition of ash increased the optimum moisture content in the compaction tests. The increase in optimum moisture content contributes to the increase of the stabilized soil's capacity. Chauhan *et al.* [7] observed that optimum moisture content increases and sand maximum dry density decreases with increased percentage of fly ash mixed with silty sand. Bhatta N. [8] concluded that the addition of river sand to pond ash improved the CBR value so that it could be used for construction of sub-grade. Prasad *et al.* [9] studied the behavior of reinforced fly ash sub-base for flexible pavement and it was seen that with increase in reinforcement CBR was improved. To enhance the utilization of fly ash in road works, demonstration projects on construction of rural roads using fly ash were taken up by Central Road Research Institute (CRRI). Many researchers have carried out the investigation on soil, fly ash and soil fly ash mixtures. So far the combination of fly ash, river sand and ceramics (used in construction) has not been studied in detail [10–18].

SCOPE AND OBJECTIVES

In the present study, an attempt is made to identify how fly ash and ceramics may be effectively utilized in combination with the clayey soil to get an improved soil material which may be used in various soil structures. Fly ash used was obtained from ACC Cement factory, Bilaspur, Himachal Pradesh. Locally available clayey soil and Beas sand has been used in this experimental investigation.
Following are the objectives of the present work:

1. Clay and Beas sand were mixed in varying percentages and optimized for maximum dry density.
2. Fly ash content is varied from 5 to 20% to optimize its value on maximum dry density and CBR value of suitable clay-sand mixes.
3. The CBR value of the most appropriate combination of the three materials with varying percentage of waste ceramics has been studied at the optimum moisture content and maximum dry density.
4. The best composition of the mix has been worked out on the basis of MDD and CBR values.

ENGINEERING PROPERTIES OF MATERIALS USED

The materials used in the study were locally available soil, fly ash (FA), sand and ceramics (indicated as Cer. in Table 1).

Method of Testing

The laboratory studies were carried out in following phases:

- Various index properties of clay, sand, fly ash and ceramics were determined.
- The modification of soil by adding sand in varying percentages of 10, 20, 30, 40, 50%.
- Modification of soil with 30 and 40% of sand and fly ash in varying percentages in

the range of 5 to 40% with the increment of 5%.

- For the best optimized composition of soil-sand-fly ash (70%–30%–5% and 70%–30%–10%), adding the ceramic in the range of 2 to 8% with increment of 2%.
- Modification of soil with 20% foundry sand and varying steel chip content in the range of 1 to 4% with increment of 1%.

The blending operation was carried out manually and care was taken for uniform mixing. Laboratory tests were carried out in accordance with the specification of relevant Indian Standards. In the initial phase of the work, the properties like moisture-density relation were evaluated for the soil blended with varying percentages of sand. For the optimized composition of clay-sand, CBR (unsoaked) is done and effect of addition of fly ash and ceramics on CBR as well as compaction characteristics are studied [16–20].

Table 1: *Properties of Used Materials.*

Particulars of test	Soil	FA	Sand	Cer.
Specific gravity	2.57	2.34	2.63	1.84
Coefficient of uniformity (Cu)	2.38	5.72	3.61	7
Coefficient of curvature (Cc)	1.23	0.64	0.74	1.08
IS soil classification	CL-ML	SW	SP	-
Liquid limit (%) IS: 2720 (Part V)	21.75	41.2	NP	NP
Plastic limit (%)	17.48	NP	NP	NP
Max. dry density (g/cc)	1.83	1.22	2.01	1.48
Optimum moisture content (%)	15.5	28.5	9	21

Particle-size distribution curves for soil, fly ash and sand are shown in Figure 1 (IS: 2720 (Part IV) 1975).

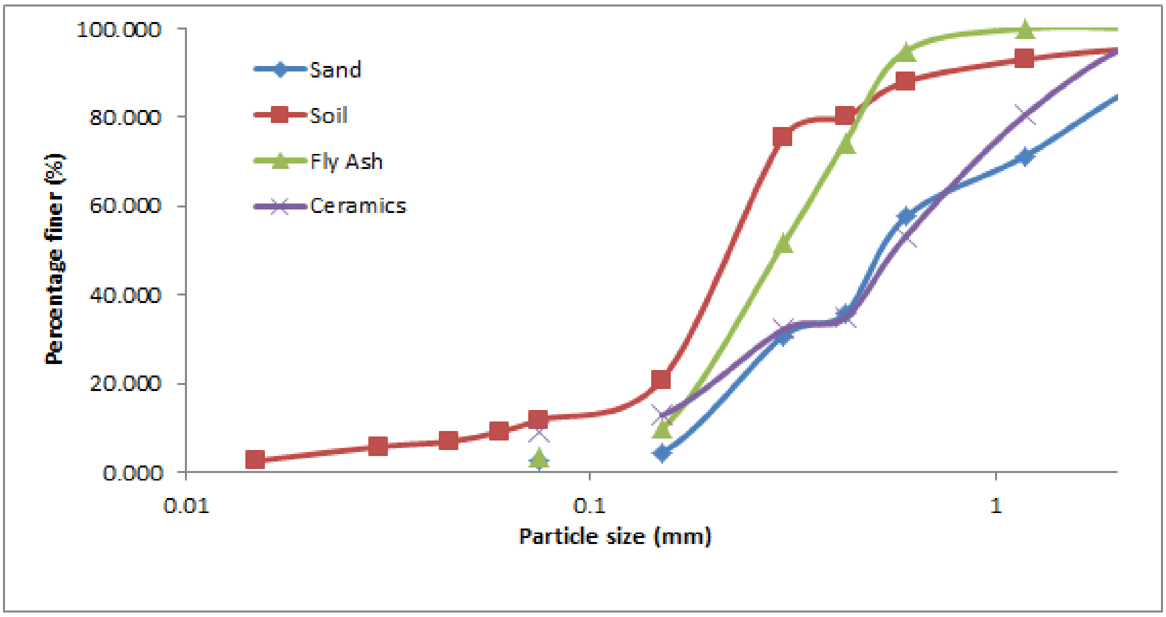

Fig. 1: *Particle Size Distribution of Soil, Sand, Fly Ash and Ceramics.*

RESULTS AND DISCUSSION

Compaction Characteristics

IS Light compaction tests were carried out on different proportions of foundry sand and soil in accordance with the procedure laid in IS: 2720 (Part VII) 1980/87 so as to study their moisture –density relationship. Figure 2 shows the variation of optimum moisture content (OMC) and corresponding maximum dry density respectively for different percentages of sand mixed in the soil. Figure 2 shows that the value of OMC decreases and MDD value increases with increase in sand content. Hence, 70C:30S and 60C:40S (Table 2) are chosen as Mixture A, and fly-ash was added to it to make Mixture B. After conducting the Procter tests on various combinations of clay and sand, the best combinations on the basis of MDD & OMC were chosen. 70% clay + 30% sand and 60% clay + 40% sand were found best in all and further Proctor test were done with fly ash. From this, the best combination was obtained. The compaction characteristics of material for clay:sand:fly ash were found out with standard Proctor Test as per procedure of IS: 2720 (Part VII) 1980/87. In the compaction characteristics, maximum dry density and optimum moisture content of material were found out. The test results for 70% clay + 30% sand + fly-ash are as shown in Figure 3.

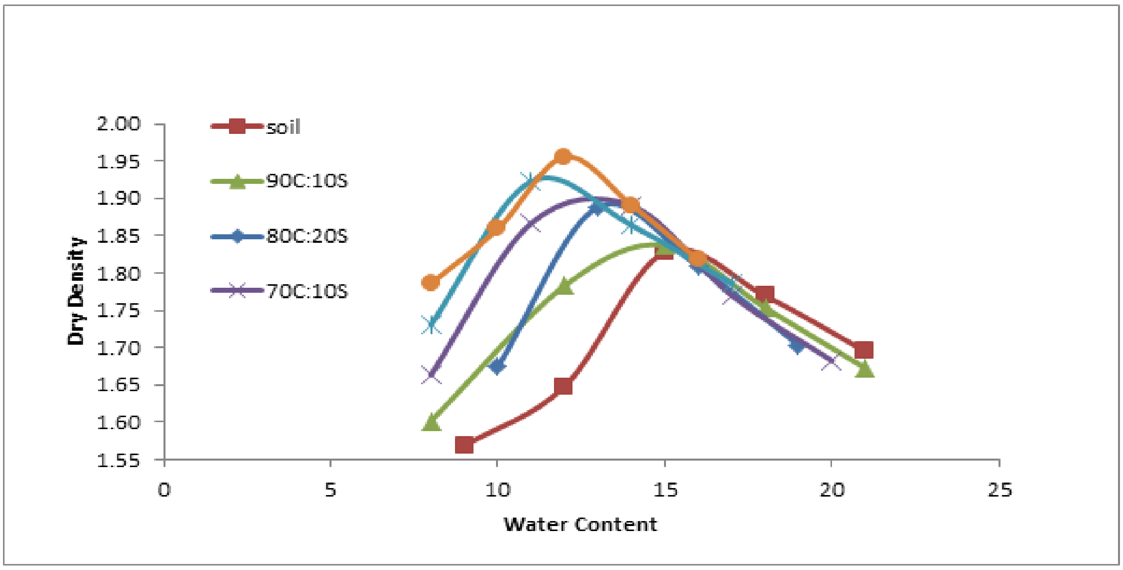

Fig. 2: *Variation of MDD and OMC with Increase in Sand Content.*

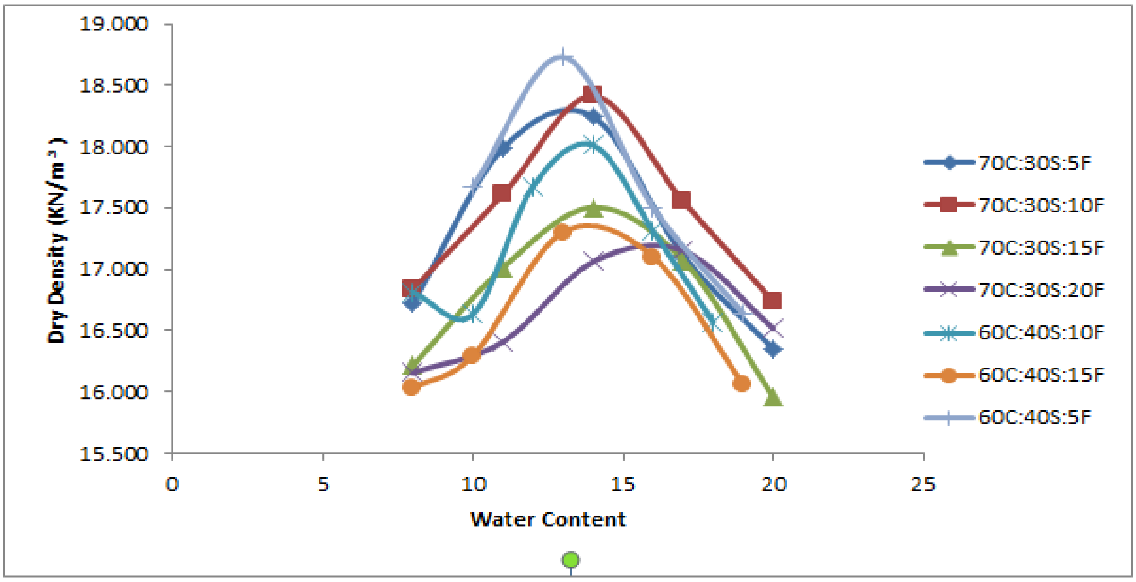

Fig. 3: *Variation of MDD and OMC with Increase in Fly Ash Content.*

By increasing the fly ash percentage insoil-sand composition (70%–40% and 60%–40%), there is an increase in optimum moisture content and decrease in maximum dry density. This variation in OMC and MDD can be seen in Figure 3. Figure 4 shows the relationship between the percentage of F/A and MDD, in which MDD is represented by '*y*' and water content is represented by '*x*'. After conducting the Procter tests on various combinations of clay and sand, the best combinations on the basis of MDD and OMC were chosen. It was found that adding 5% of fly ash provides enough strength and gives best results in Proctor tests conducted. From this, the best combination was obtained. Ceramics was added in percentage of total weight of the mix, i.e., the clay + sand + fly ash. The standard Proctor test as per procedure laid down in IS: 2720 (Part VII) 1980/87 was performed on various combinations of clay + sand + F/A and ceramics as shown in *Figure 5*.

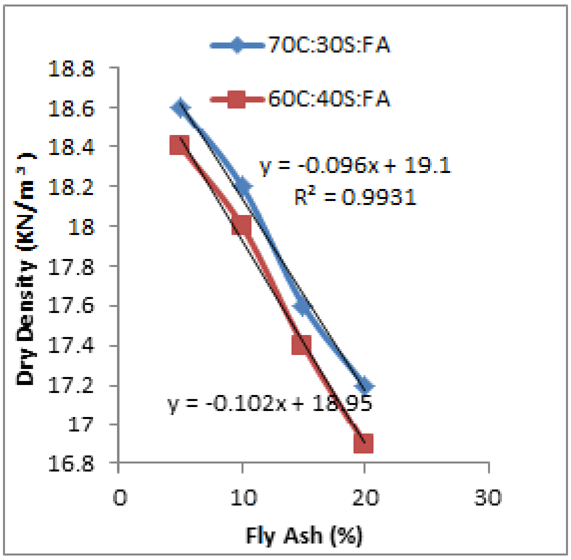

Fig. 4: *Relationship between MDD and Fly Ash Content.*

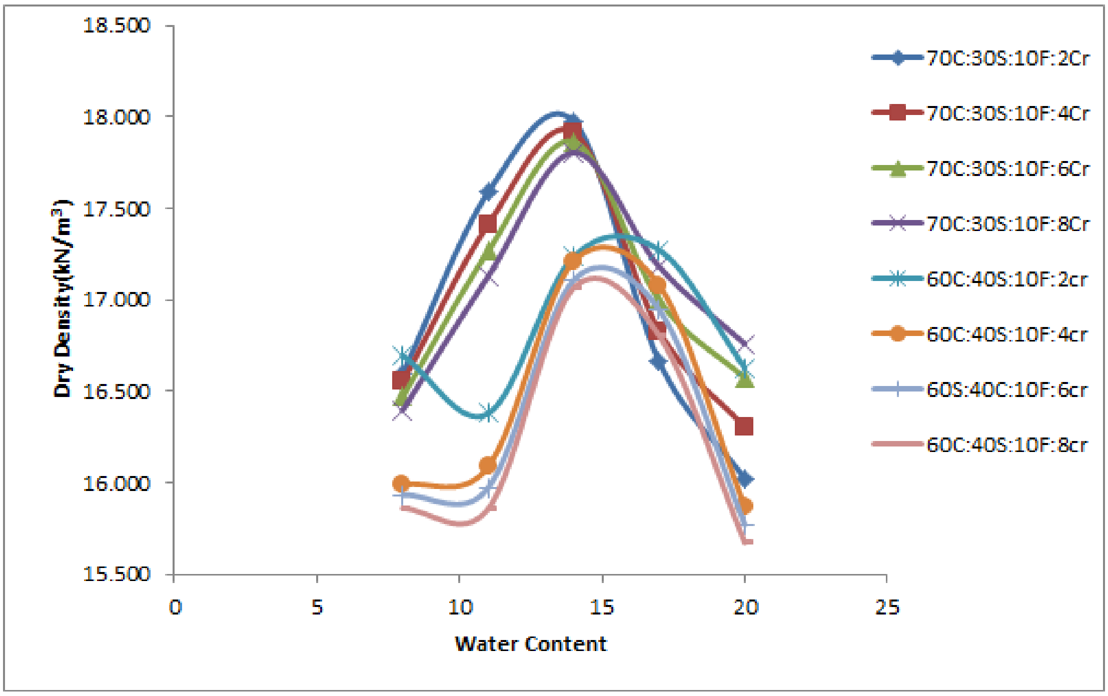

Fig. 5: *Graph showing Variation of Curves due to Addition of Ceramics.*

From Figure 5, we can see that maximum dry density comes with 2% ceramics in the mixture and the variation with ceramics shows that there is a decreasing trend in MDD with increase in ceramics. The computer-controlled tests were conducted for clay, sand, fly ash and ceramic combination as per guidelines laid by IRC. The experimental investigations were conducted for unsoaked conditions. The values of CBR for different proportions are shown in Table 2.

Table 2: *CBR Values of Various Proportions.*

Combination	**CBR (%)**
Clay	5.11
Clay:Sand::70:30	8.58
Clay:Sand::60:40	9.36
Clay:Sand:FA:: (70:30:10)	12.70
Clay:Sand:FA:: (60:40:10)	12.18
Clay:Sand:FA:Cer.::70:30:10:2	14.44
Clay:Sand:FA:Cer.::70:30:10:4	14.11

CONCLUSIONS

Fly ash is a waste produced by burning of coal in thermal plants and has low specific gravity and CBR value. The addition of sand, ceramics and fly ash improves the properties of the composite thus formed, and allows its application in the construction of roads leading to safe disposal of fly ash. Based upon the above Study, the following conclusions can be drawn.

1. The gradation of soil was gradually altered by adding sand to it. The addition of sand resulted in an increase in MDD and decrease in OMC. Further, there was also a significant increase in the CBR value with the addition of sand. The ratios of 60C:40S and 70C:30S were taken as base mixture and all further tests (with the addition of other ingredients) were conducted on them.
2. The composites of 60C:40S and 70C:30S were further tested with the addition of fly ash in them. The addition of fly ash further led to a decrease in MDD but there was also an increase in the CBR value and the composite was found to be more stable. Out of all ratios, the most stable was with 10% of fly ash and compaction tests were done on ratios (60C:40S):10F and (70C:30S):10F.
3. The composites of (60C:40S):10F and (70C:30S):10F were further tested with the addition of ceramics in them. The addition of ceramics further led to a decrease in MDD but there was an increase in the CBR value and the composite was found to be more stable. Out of all ratios, the most stable was with 2% of ceramics.
4. Permeability value increased with the addition of sand in the soil-sand mixture. Further addition of fly ash in the composite resulted in the decrease in permeability and addition of ceramics increased the permeability.

Based on the results, it was suggested that 70(soil):30(sand):10(fly ash):2(ceramics) was the best composite mixture. The final composite was having the CBR value of 14.44% and MDD of 18.0 KN/m^3 and permeability of 2.56×10^{-5} m/s. The final composite can be considered for applications in construction of embankments, soil sub-grade and foundation bases particularly in rural roads and low-cost roads.

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