Evaluation of Geotechnical Properties of Local Clayey Soil Blended with Waste Materials

Babita Singh [1] and Ravi Kumar Sharma [2]

[1] Post Graduate Student, Department of Civil Engineering, National Institute of Technology, Hamirpur, India.
E-Mail: babitassingh1@gmail.com
[2] Professor, Department of Civil Engineering, National Institute of Technology, Hamirpur, India.
E-Mail:rksnithp61@gmail.com

ABSTRACT

Nowadays, disposal of waste materials has become a matter of serious concern due to environmental and ecological issues. In this paper, an attempt is made to determine an optimum proportion mix suitable for geotechnical applications by blending the locally available clayey soil with sand, fly ash, tile waste and jute fibers. This optimum mix provides a cheaper construction material and helps in effective utilization of waste materials like fly ash and tile waste; thus solving the problem of disposal of waste materials to some extent. In this research, the percentage of waste materials added to the clayey soil to make the optimum mix is obtained on the basis of compaction characteristics and the optimum mix is further checked for strength and permeability characteristics. The basic idea behind this study is to explore the collective benefit of the material properties of waste materials when used in a composite form. It can be revealed from this study that mixing of waste materials brings out significant improvement in geotechnical properties of locally available clayey soil. From economic analysis, it can be concluded that the optimum mix obtained in this study yields an improved and cheaper construction material for the construction of flexible pavement.

KEYWORDS: Waste river sand, Fly ash, Tile waste, Jute fibers, Strength and permeability characteristics, Economic analysis.

INTRODUCTION

Generation of solid wastes like fly ash, blast furnace slag, glass waste, tile waste, stone dust, etc… is increasing at a rapid rate in developing countries like India in which disposal of fly ash and tile waste is an active research study area nowadays and thus adopted as the waste materials to be used for this present study. According to the report 2011-12 of "Central Electricity Authority, New Delhi", only about 54.53% of fly ash generated from lignite based power stations is utilized. Also, about 15 to 30 MT of waste materials are produced yearly in the ceramic industries of India, a large percentage of which is tile waste. The open heaps of these waste materials produce unaesthetic views and cause environmental hazards. So, there is an urgent need of their utilization. In the field of stabilization of poor soils, they can be used effectively. Many geotechnical researchers have contributed in this field.

Zhang and Xing (2002) reported that stabilization of expansive soil can be successfully done with the help of lime and fly ash. On mixing lime and fly ash, texture of expansive soil changes. Maximum dry density decreases while optimum moisture content and California bearing ratio (CBR) values increase with increasing the amount of lime and fly ash.

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Bhuvaneshwari et al. (2005) revealed that workability increases with 25% fly ash and the maximum dry density is obtained for this proportion. Rao et al. (2008) observed that on adding fly ash maximum dry density increases and optimum moisture content decreases up to a certain fly ash content called “optimum fly ash content”; while the trend gets reversed on increasing the fly ash content beyond this optimum fly ash content. On the basis of unconfined compressive strength test study, Brooks (2009) investigated that failure stress and strain increase by 106% and 50%, respectively on addition of fly ash from 0 to 25%. Rao et al. (2009) concluded that addition of fly ash affects the dry weight of soil because the void spaces between soil solids are filled up by fly ash. Bose (2012) reported that fly ash has a good potential of improving the engineering properties of expansive soil. Khan (2012) revealed that CBR value considerably improves for the soil with fly ash layers. Sharma et al. (2012) concluded that UCS and CBR of soil increase substantially on addition of 20% fly ash and 8.5% lime. Takhelmayum et al. (2013) exhibited the improvement in strength characteristics of soil on adding coarse fly ash. Many more researchers, like: (Ingles and Metcalf, 1972; Mitchell and Katti, 1981; Brown, 1996; Cokca, 2001; Consoli et al., 2001; Senol et al., 2002; Phanikumar, 2004; Kumar, 2004; Edil et al., 2006; Rao and Subbarao, 2009; Ahmaruzzaman, 2010; Tastan et al., 2011; Muntohar, 2012 etc…) showed the effectiveness of use of fly ash in improving the properties of soil.

Sabat (2012) concluded that on increasing the content of ceramic dust, liquid limit, plastic limit, plasticity index, optimum moisture content and swelling pressure decrease while maximum dry density, unconfined compressive strength, California bearing ratio value and angle of internal friction increase. Ameta et al. (2013) observed that with the addition of ceramic waste to dune sand, improvement in MDD, CBR and shearing resistance occurs. Researchers, like: (Brito et al., 2005; Binci, 2007; Cabrel et al., 2010; Pacheco, 2011; Tabak, 2012 etc…) showed the successful application of tile waste to be used as a construction material in concrete production.

Soil reinforcement is a well-known procedure for improving the properties of problematic soil. Use of jute fibers as reinforcing fibers is a cost-effective and eco- friendly technique as jute fiber is found in abundance in India and it is also biodegradable in nature. Their effective utilization in soil stabilization can be easily validated by the experimental investigation of numerous researchers. Maheshwari (2011) indicated that the ultimate bearing capacity of clayey soil increases while the settlement at ultimate load decreases on mixing clayey soil with randomly distributed fibers. Agarwal (2011) concluded that maximum dry density decreases while optimum moisture content of sub-grade soil increases on inclusion of jute fiber. Also, mixing of bitumen coated jute fiber increases the California bearing ratio value up to 250%. Manjunath (2013) proved substantial improvement in CBR, UCS and compaction characteristics of soil through his experimentation.

The available literature shows that only a limited amount of experimentation is done with tile waste as an additive for soil stabilization. Most of the present application of tile waste is in concrete technology. Also, in most of the studies, either fly ash is used alone as a stabilizing agent, fly ash-lime combination is used or soil reinforcement with fibers is done independently. This study is intended to find out the beneficial effects of composite form of clayey soil with sand, fly ash, floor tile waste and jute fiber.

ENGINEERING PROPERTIES OF MATERIALS USED

Clay: According to ASTM D2487-10, locally available clayey soil used in this study can be categorized as CL type; i.e., clay of low plasticity. The physical properties of clay are given in Table 1.

Sand: The sand used in this experimental investigation is Beas river sand which is poorly graded. Basic physical properties of sand used are given in Table 2.

Table 1. Physical properties of clay

PROPERTY TESTED	VALUE
Specific gravity	2.63
Liquid limit (%)	42.83
Plastic limit (%)	22.49
Plasticity index (%)	20.34
Soil classification	CL
Optimum moisture content (%)	12.0
Maximum dry density (gm/cc)	1.926
Coefficient of permeability (cm/s)	1.46×10^{-7}
Unconfined compressive strength (kPa)	246.48
Soaked California bearing ratio value (%)	2.75
Unsoaked California bearing ratio value (%)	5.42

Table 2. Physical properties of sand

PROPERTY TESTED	VALUE
Specific gravity	2.634
Coefficient of uniformity, C_u	1.78
Coefficient of curvature, C_c	1.04
Optimum moisture content (%)	6.77
Maximum dry density (gm/cc)	1.585
Coefficient of permeability (cm/s)	2.65×10^{-3}

Fly ash: Fly ash collected from Ropar thermal power plant is used in this experimental investigation. It is class F category fly ash. Class F fly ash is basically obtained from the burning of anthracite and bituminous coals. It has low calcium content. Physical and chemical properties of fly ash used in this study are given in Table 3 and Table 4, respectively.

Tile waste: Floor tile used in this study was obtained from the construction site of Ambika girls' hostel, National Institute of Technology, Hamirpur. It has a specific gravity of 2.39. The tile waste was crushed into the size range of 4.75mm to 75µm with the help of a hammer for experimental use.

Jute fiber: The chemical composition of jute fiber used in this study is given in Table 5.It was obtained from waste jute bags and was cut into pieces of a length of 12 mm for experimental use.

TESTING METHODOLOGY ADOPTED

All the laboratory tests were conducted in accordance with ASTM standards as shown in Table 6.

Table 3. Physical properties of fly ash

PROPERTY TESTED	VALUE
Specific gravity	1.97
Liquid limit (%)	40.2
Optimum moisture content (%)	31.6
Maximum dry density(gm/cc)	1.166
Coefficient of permeability(cm/s)	5.56×10^{-5}

Table 4. Chemical composition of fly ash

CONSTITUENT	PERCENTAGE
Silica (SiO_2)	59.45
Alumina (Al_2O_3)	27.15
Iron oxide (Fe_2O_3)	7.31
Calcium oxide (CaO)	2.35
Magnesium oxide (MgO)	0.59
Sulphur tri oxide (SO_3)	0.90
Loss of ignition	2.25
Soaked California bearing ratio (%)	1.97

Table 5. Chemical composition of jute fiber

CONTENT	PERCENTAGE
α-cellulose	60
Hemicellulose	23
Lignin	14
Fats and waxes	1.0
Nitrogenous matter	1.4
Ash content	0.5
Pectin	0.2

The laboratory tests were conducted according to the following steps:

1. A series of proctor compaction test were conducted on clay mixed with different percentages of sand; i.e., 10%, 20%, 30% and 40%. Then, the most optimum clay-sand mix proportion; i.e., the proportion with largest maximum dry density, was

chosen for further modification. The purpose of mixing sand with clay was to make the blending process easy and convenient as well as to satisfy the criteria of good soil for mix design.

2. The optimum clay-sand mix obtained was blended with different percentages of fly ash; i.e., 10%, 15%, 20% and 25%. Standard proctor tests were carried out on each mix to obtain the most appropriate clay-sand-fly ash mix.
3. The mix selected as the most appropriate clay-sand-fly ash mix has further undergone standard proctor compaction test with different percentages of floor tile waste; i.e., 3%, 6%, 9% and 12%, then the most optimum clay-sand-fly ash-tile waste mix was chosen.
4. The optimized clay-sand-fly ash-tile waste mix was further reinforced with different percentages of jute fiber; i.e., 0.25%, 0.5% and 0.75% by weight to find out the most appropriate mix proportion of clay-sand-fly ash-tile waste-jute fiber on the basis of compaction characteristics.
5. After choosing optimum mixes for all the combinations; i.e., optimum mixes of clay-sand, clay-sand-fly ash, clay-sand-fly ash-tile waste, clay-sand-fly ash-tile waste-jute fiber on the basis of compaction characteristics; all the optimum mixes have undergone California bearing ratio test, unconfined compressive strength test and permeability test to analyze the positive change in strength and permeability characteristics of locally available clayey soil on every modification.

Also, in order to avoid the effect of remolding of soil, fresh soil sample was taken each and every time. This is because the clayey soil used was sensitive.

DESCRIPTION OF TEST PROCEDURES FOLLOWED

Standard proctor test: For all the compaction tests to be performed, sample mixes were prepared by first mixing the dry soil and the materials in the required percentage on dry weight basis. The mould of standard volume equal to 1000cc is filled up with the material to be compacted in three layers. Each layer is compacted by 25 blows of standard hammer weighing 2.45kg falling through a height of 12".Test is repeated at different water contents. Dry density is calculated every water content so as to obtain the compaction curve between moisture content and dry unit weight. The water content corresponding to maximum dry density achieved is taken as the optimum moisture content.

Table 6. ASTM standards for different tests

TEST	ASTM STANDARD
Hydrometer analysis	ASTM D422-63
Standard proctor test	ASTM D698-07e1
Specific gravity	ASTM D854-10
Unconfined compressive strength test (UCS)	ASTM D2166-13
Soil classification (USCS)	ASTM D2487-11
Consistency limit tests	ASTM D4318-10
Particle size distribution	ASTM D6913-04
Falling head permeability test	ASTM D5084-03
California bearing ratio test (CBR)	ASTM D1883-05

Table 7. Coefficient of permeability of optimum mixes

OPTIMUM MIXES	COEFFICIENT OF PERMEABILITY (cm/s)
100% clay	1.44×10^{-7}
70% clay: 30% sand	6.55×10^{-7}
63% clay: 27% sand: 10% fly ash	1.688×10^{-6}
63% clay: 27% sand: 10% fly ash: 9% tile waste	2.702×10^{-6}
63% clay: 27% sand: 10% fly ash: 9% tile waste: 0.5% jute fiber	3.01×10^{-6}

Falling head permeability test: Permeability tests were carried out by falling head method. For permeability test, sample is compacted at optimum moisture content in three layers in the standard permeability mould to achieve maximum dry density. The samples were saturated before conducting the test. After saturating the sample, a stand pipe of known cross-sectional area is fitted over the permeameter and water is allowed to run down. After achieving steady flow, observations are taken in the form of head and time interval so as to calculate the coefficient of permeability by the formula:

$$k = \frac{2.303aL}{At} log \frac{h1}{h2}$$

where,

a=cross-sectional area of stand pipe.

L= length of soil column.

A= area of soil column.

t = time required for head drop.

h_1=initial head.

h_2= final head.

California bearing ratio (CBR) test: To prepare the samples for CBR test, different mixes chosen were compacted statically in standard moulds at optimum moisture content and maximum dry density. The dimension of the soil sample for CBR test is taken as 150 mm diameter and 125 mm height. Surcharge weight of 50 N was used during the testing. A metal penetration plunger of 50 mm diameter and 100 mm length was used to penetrate the samples at the rate of 1.25 mm/minute using computerized CBR testing machine. Soaked CBR tests were conducted after 96 hours soaking. Soaking samples were placed in a tank maintaining constant water level throughout the period.

Unconfined compressive strength test: The unconfined compressive strength tests were conducted on the reference mixes obtained from standard compaction test. The sizes of the samples prepared were of aspect ratio 2; i.e., 38 mm diameter and 76 mm length and the strain rate of 1.25 mm/minute was used for testing. The samples were prepared by compacted sample with the help of a temping rod in three layers at optimum moisture content and maximum dry density in the UCS mould of standard dimensions.

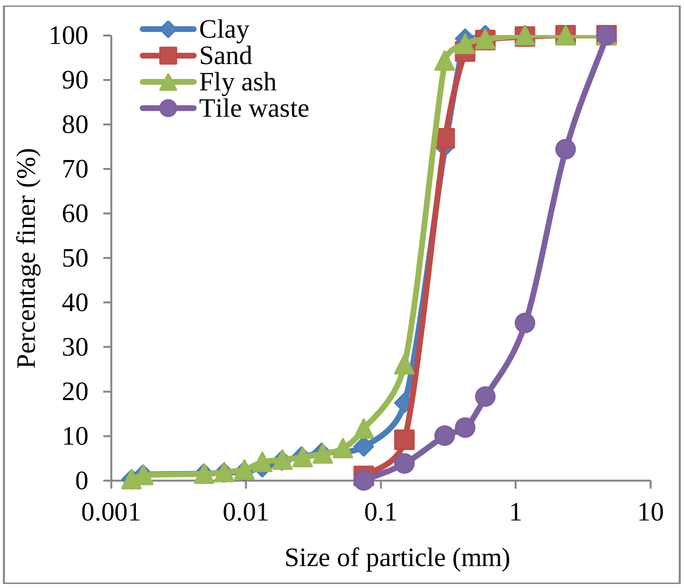

Figure (1): Particle size distribution of clay, sand, fly ash and tile waste

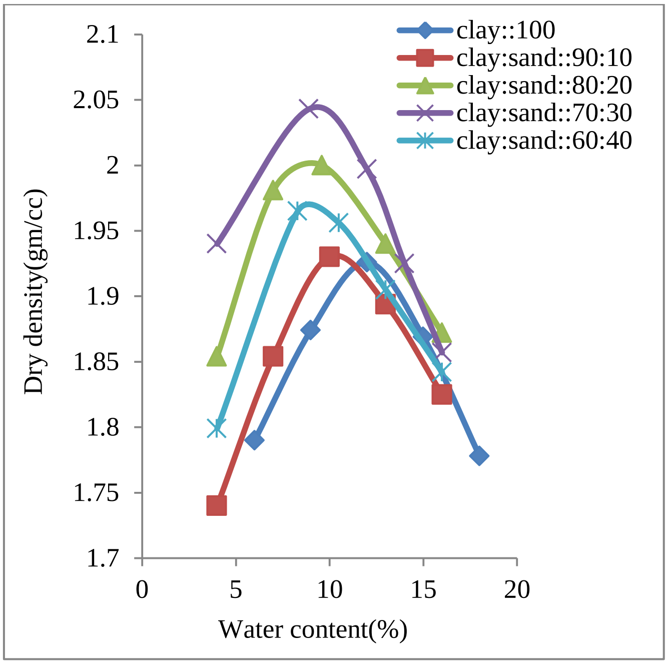

Figure (2): Compaction characteristics of clay-sand mixes

RESULTS AND DISCUSSION

Particle size distribution analysis

Particle size distribution curves of clay, sand, fly ash and tile waste are shown in Fig 1. It is revealed from the Figure that clay and fly ash are uniformly graded in nature and fly ash has larger range of finer particles while sand and tile waste show poorly graded nature.

Compaction characteristics

The clayey soil used in this study has the optimum moisture content of 12% and the maximum dry density of 1.926 gm/cc. In the first phase of compaction, when the clay is mixed with sand in the percentage variation of 10%, 20%, 30% and 40% initially the maximum dry density for the clay-sand mix increases and then decreases. The maximum dry density of the mix increases from 1.930 g/cm^3 to 2.043 g/cm^3 up to 30% sand content and then decreases from 2.043 g/cm^3 to 1.965 g/cm^3 for 40% sand content as shown in Figures 2 and 3.This trend of variation of maximum dry density for different clay-sand mixes is primarily achieved due to the alteration of gradation of particles in the mix. Initially, up to a certain percentage of sand added, the void spaces created in the clay-sand mix were filled with the fine clay particles resulting in the increase of maximum dry densities and after that, the extra amount of sand added leads to the segregation of particles in the mix causing the decrease of maximum dry density. Also, on adding sand, the optimum moisture content of the clay-sand mix decreases because of the coarse grained texture of sand particles which has smaller specific surface area and thus requires lesser amount of water to achieve maximum dry density. Variation of optimum moisture content with varying percentages of sand is also shown in Fig. 3. The relationship obtained between the percentage of variation of sand in the composite clay-sand mix and the optimum moisture content of the composite mix with the help of polynomial regression, in which optimum moisture content is represented by ‘OMC’ and percentage of sand is represented by ‘s’; can be given as:

$$OMC = 0.001s^2 - 0.156s + 11.81$$
$$R^2 = 0.966$$

70% clay-30% sand mix with maximum dry density of 2.043 g/cm^3 was selected as the optimum clay-sand mix. Fly ash was mixed in this optimum clay-sand mix in different percentages varying from 10% to 25% in the increments of 5% each. On increasing the percentage of fly ash in the optimum clay-sand mix, the maximum dry density decreases from 2.043 g/cm^3 to 1.761 g/cm^3 as shown in Figures 4 and 5. This happened because of the lower specific gravity of fly ash in comparison to that of clayey soil and sand used in this study. Therefore, the mix clay:sand:fly ash: 63:27:10 was selected as the most appropriate clay-sand-fly ash mix proportion.The relationship obtained between the percentage of variation of fly ash in the composite clay-sand-fly ash mix and the maximum dry density of the composite mix with the help of linear regression, in which maximum dry density is represented by 'MDD' and percentage of fly ash is represented by 'fa'; can be given as:

$$MDD=-0.011fa + 2.029$$
$$R^2 = 0.970.$$

The optimum moisture content of the mix increases on increasing the fly ash content because of the large specific area of fly ash particles which requires more water for sufficient lubrication needed to achieve the maximum dry density. The trend of variation of optimum moisture content with increasing percentage of fly ash is shown in Figure 5. The relationship obtained between the percentage of variation of fly ash in the composite clay-sand-fly ash mix and the optimum moisture content of the composite mix with the help of polynomial regression, in which optimum moisture content is represented by 'OMC' and percentage of fly ash is represented by 'fa'; can be given as:

$$OMC = -0.001fa^2 + 0.193fa + 8.904$$
$$R^2 = 0.998.$$

On addition of tile waste in the most appropriate clay:sand:fly ash: 63:27:10 mix having maximum dry density of 1.913 gm/cc in different percentages; i.e., 3%, 6%, 9% and 12% the maximum dry density of the mix increases up to 9% tile waste and then decreases for 12% tile waste as shown in Figures 6 and 7. The increase in maximum dry density due to the addition of tile waste in the mix takes place due to the better packed orientation of particles achieved as the void spaces of the mix are filled by the tile waste. But after a certain percentage, the additional amount of tile waste contributes towards the segregation of the mix resulting in the decrease of maximum dry density.Variation of optimum moisture content of the different clay-sand-fly ash-tile waste mixes does not follow any specific trend.

Clay:sand:fly ash:tile waste: 63:27:10:9 mix was selected as the optimum mix to be reinforced with the varying percentages of jute fibre. Increase in jute fibre percentage imparts slight increment in the maximum dry density intially while the maximum dry density of the mix decreases on further addition of the jute fiber due to the lighter weight of jute fibers and the flocullated arrangement of the particles obtained in the mix on inclusion of jute fibers as shown in Figures 8 and 9. Inclusion of jute fibers in the clay-sand-fly ash-tile waste mix does affect the optimum moisture content to a great extent. Therefore, the mix clay:sand:fly ash:tile waste:jute fiber 63:27:10:9:0.50 was selected as the most appropriate and optimum clay-sand-fly ash mix proportion.

California bearing ratio (CBR) test results

Soaked and unsoaked California bearing ratio tests were carried out on all the optimum mixes selected on the basis of compaction characteristics; i.e., clay:sand: 70:30, clay:sand:fly ash: 63:27:10, clay:sand:fly ash:tile waste: 63:27:10:9 and clay:sand:fly ash:tile waste:jute fiber: 63:27:10:9:0.5. The treated optimum mixes have undergone CBR test to evaluate their load bearing capacity and their suitability to be used as a construction material for sub-gragde. All the optimum mixes prepared by compacting the sample at MDD and OMC were tested in soaked and unsoaked condition by light compaction method.As expected, the unsoaked CBR values achieved for all the optimum mixes were higher than those of the soaked CBR values.The trend of variation of soaked and unsoaked CBR values of all the optimum mixes are shown in Figure 10. It is observed that soaked CBR

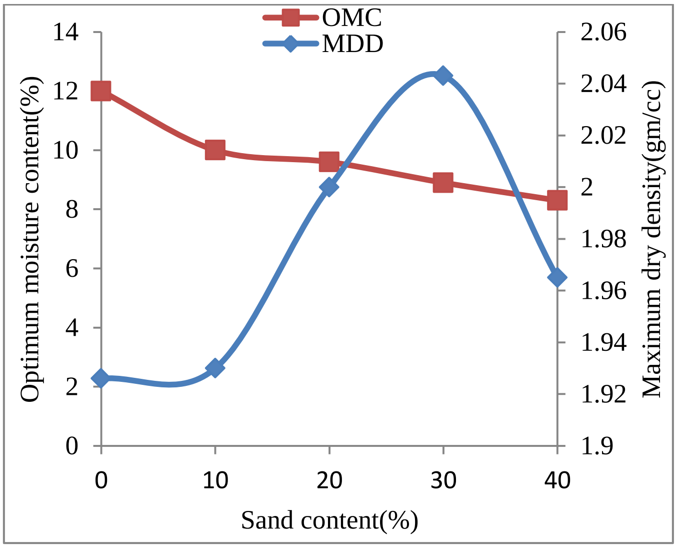

Figure (3): Variation of optimum moisture content and maximum dry density of clay-sand composite with sand content

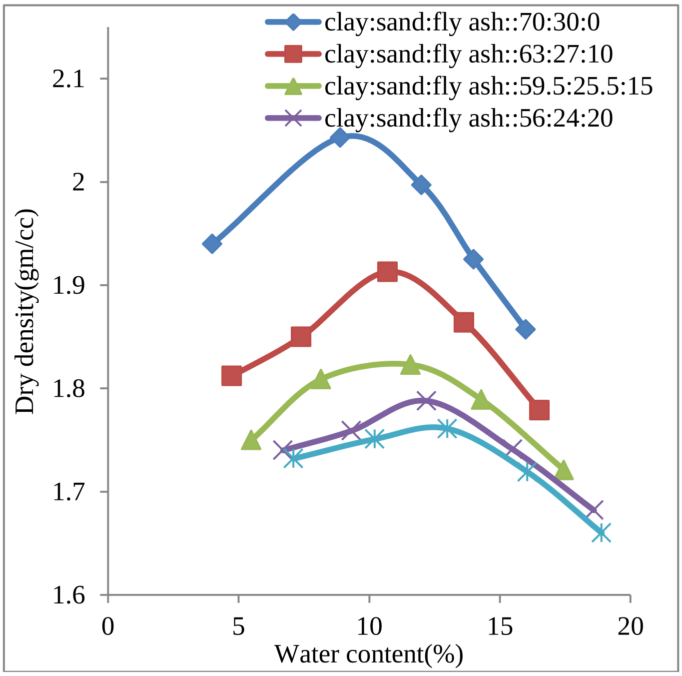

Figure (4): Compaction characteristics of clay-sand-fly ash mix

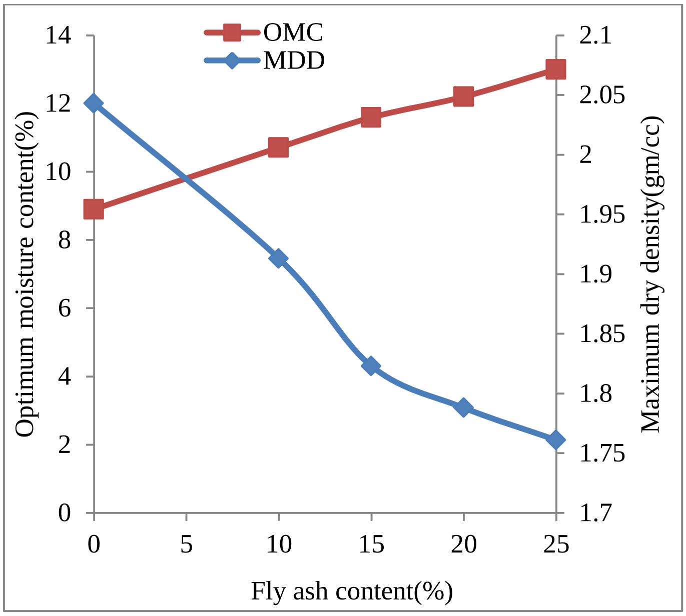

Figure (5): Variation of optimum moisture content and maximum dry density of clay-sand-fly ash mix with fly ash content

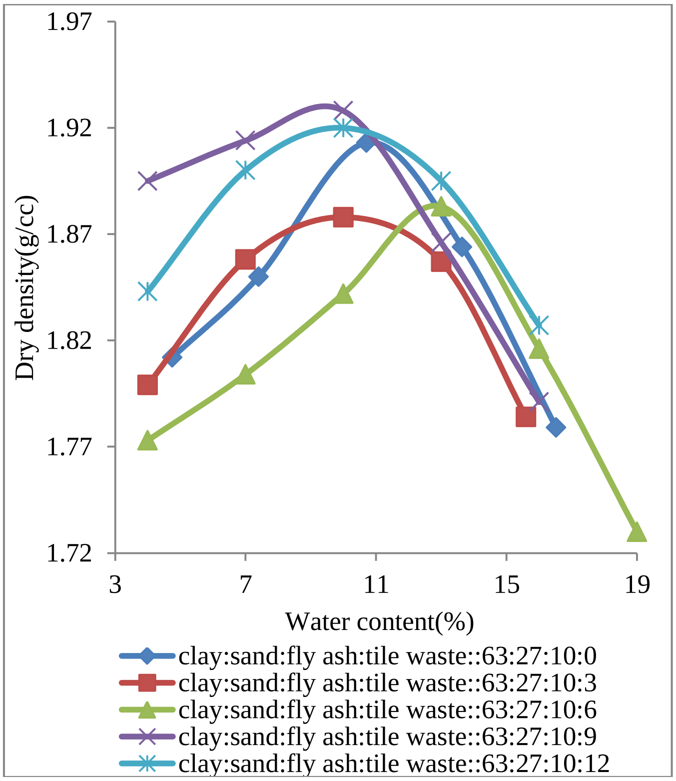

Figure (6): Compaction characteristics of clay-sand-fly ash-tile waste mix

value of clayey soil increases from 2.75% to 6.55% for the final optimum mix of clay:sand:fly ash:tile waste:jute fiber: 63:27:10:9:0.50 while the unsoaked CBR value of clayey soil increases from 5.42% to 12.99% for the final optimum mix of clay:sand:fly ash:tile waste:jute fiber: 63:27:10:9:0.5. This improvement in the CBR values probably happened because of the better compaction and packing characteristics of the particles achieved with the introduction of additives in the pure clayey soil.

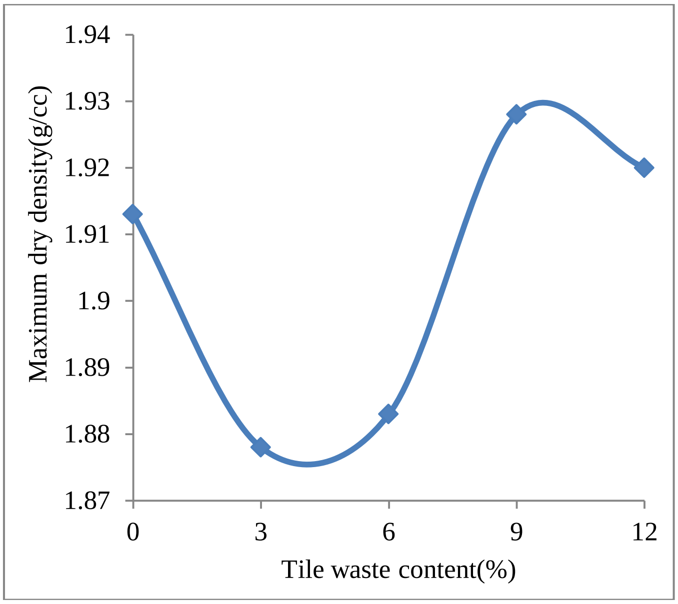

Figure (7): Variation of maximum dry density of clay-sand-fly ash-tile waste mix with tile waste content

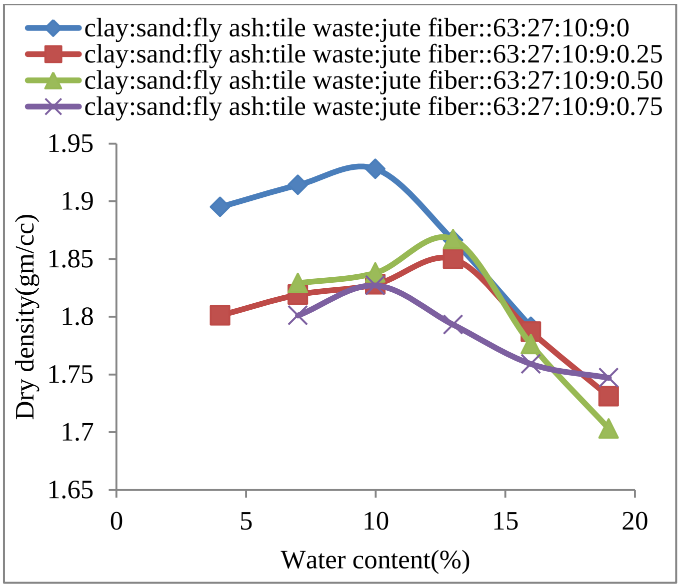

Figure (8): Compaction characteristics of clay-sand-fly ash-tile waste-jute fiber mix

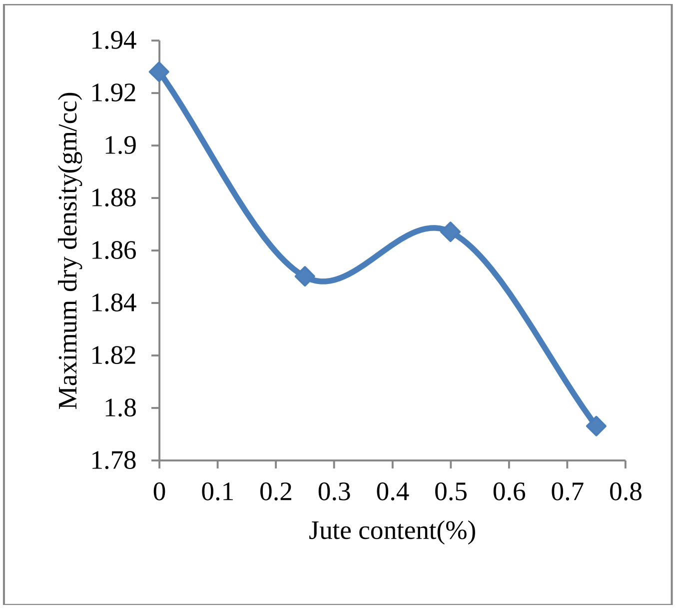

Figure (9): Variation of maximum dry density of clay-sand-fly ash-tile waste-jute fiber mix with jute fiber content

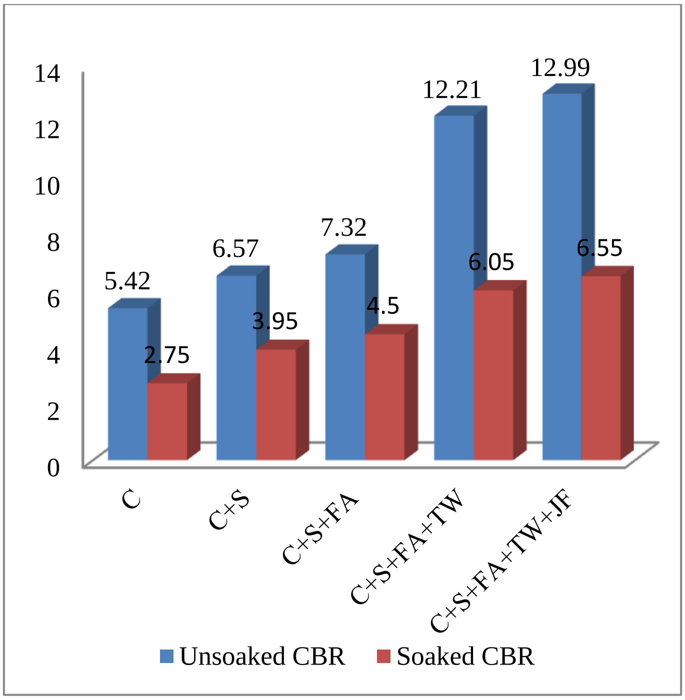

Figure (10): Variation of unsoaked and soaked CBR values for various optimum mixes (C – clay, S – sand, FA – fly ash, TW – tile waste and JF – jute fiber)

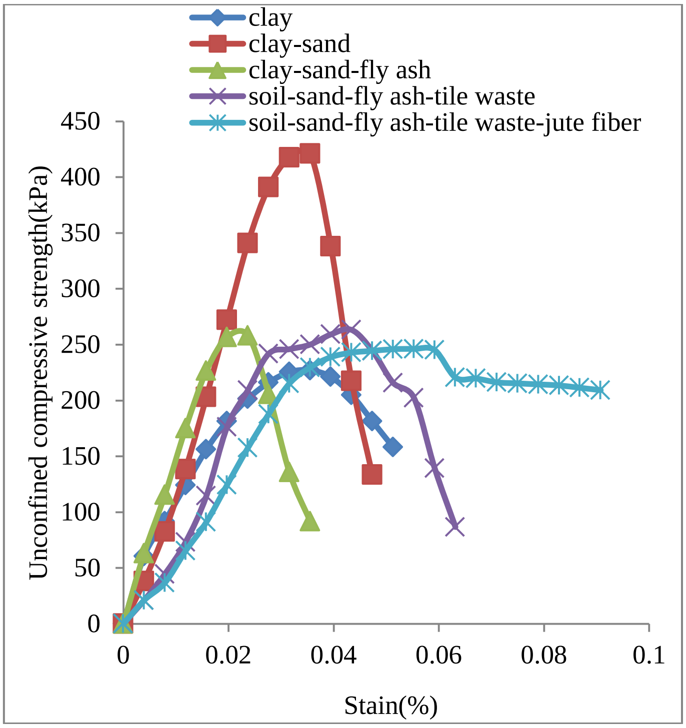

Figure (11): Stress-strain behavior of clay, clay-sand, clay-sand-fly ash, clay-sand-fly ash-tile waste and clay-sand-fly ash-tile waste-jute fiber mixes

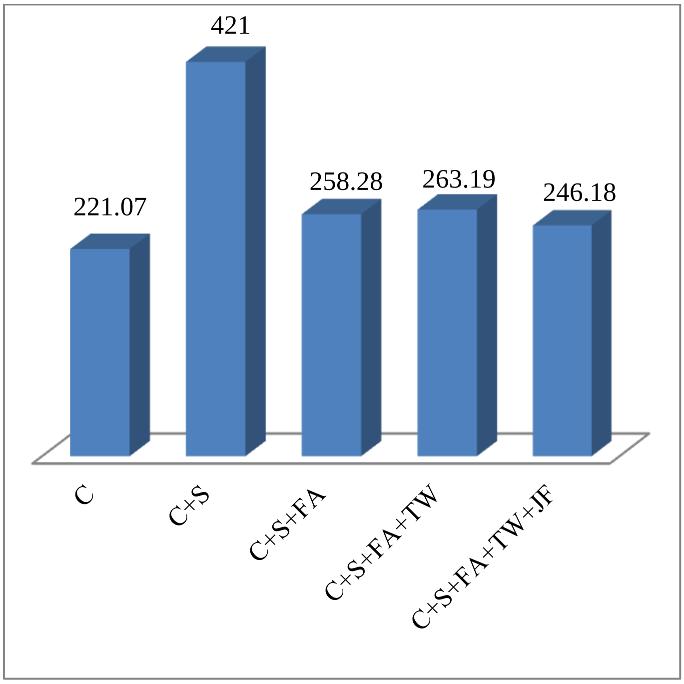

Figure (12): Variation of unconfined compressive strength for various optimum mixes (C – clay, S – sand, FA – fly ash, TW – tile waste and JF – jute fiber)

Unconfined compressive strength test results

The unconfined compressive strength tests were conducted on the optimum mixes obtained from standard compaction. The stress-strain behaviors of different composites are shown in Figure 11. Unconfined compressive strength of clay used in this study was 221.07 kN/m^2. Variation observed in the values of unconfined compressive strength for different optimum mixes are shown in Figure 12. For all the optimum mixes, the value of unconfined compressive strength is greater than that of pure clay. Though the value of unconfined compressive strength for the final optimum mix clay:sand:fly ash:tile waste:jute fiber: 63:27:10:9:0.5 is not appreciably more than that of pure clay, the addition of jute fibers surely improved the strain energy absorption capacity of the mix which can be seen from Figure 11.

Permeability test results

The coefficients of permeability of clay, sand and fly ash determined by using falling head permeability test are: 1.46x10^{-7}cm/s, 2.65x10^{-3}cm/s and 5.56x10^{-5} cm/s, respectively. The coefficient of permeability of clay increases on addition of sand, fly ash, tile waste and jute fiber. The variation of coefficient of permeability of optimum mixes is shown in Table 7.This increase in permeability occurs because on the addition of sand, fly ash and tile waste the mix exhibits coarser mature than that of pure clay and the addition of jute fibers will provide more number of passage paths to the fluids resulting in the improvement of permeability characteristics.

ECONOMIC ANALYSIS FOR THE DESIGN OF FLEXIBLE PAVEMENT

Figure 13 shows the required pavement thickness with cumulative traffic for soaked CBR values when the clay was stabilized by mixing appropriate percentage of each additive used and also for the unstabilized pure clay as per IRC: 37-2001 (Guidelines for the Design of Flexible Pavements). It can be seen that the pavement thickness reduces considerably for the final optimum stabilized mix; thus reducing the cost of construction of the pavement as a substantial amount of saving can be achieved in the sense of the materials needed for the construction of the pavement. Figure 14 shows the variation of the cost of pavement construction in rupees per m^2 with cumulative traffic for soaked and unsoaked CBR values of stabilized clay and pure clay calculated on the basis of Standard Schedule Rates of the area. Also, the variation of percentage saving in cost of the construction of flexible pavement with cumulative traffic for soaked CBR values is shown in Figure 15.

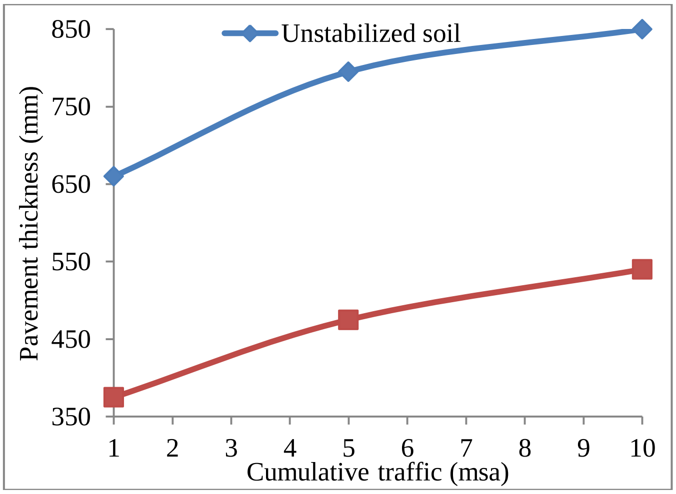

Figure (13): Variation of pavement thickness with cumulative traffic for soaked CBR values

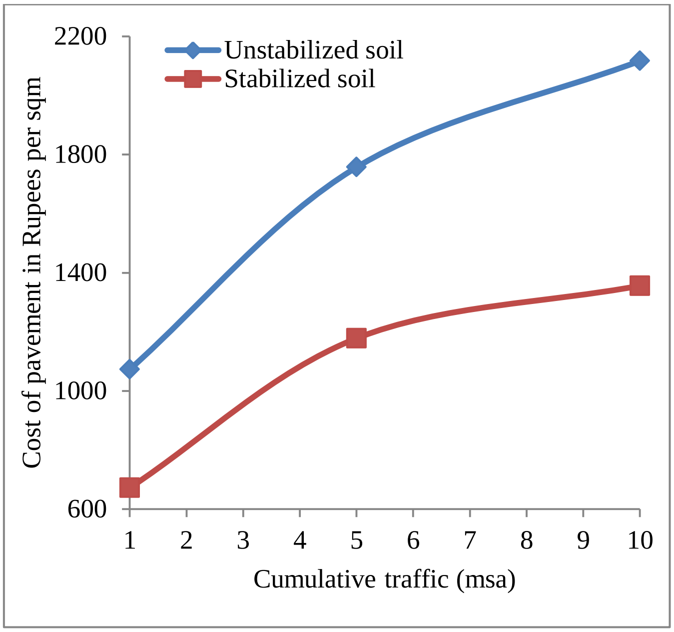

Figure (14): Variation of cost of pavement in rupees per m2 with cumulative traffic for soaked CBR values

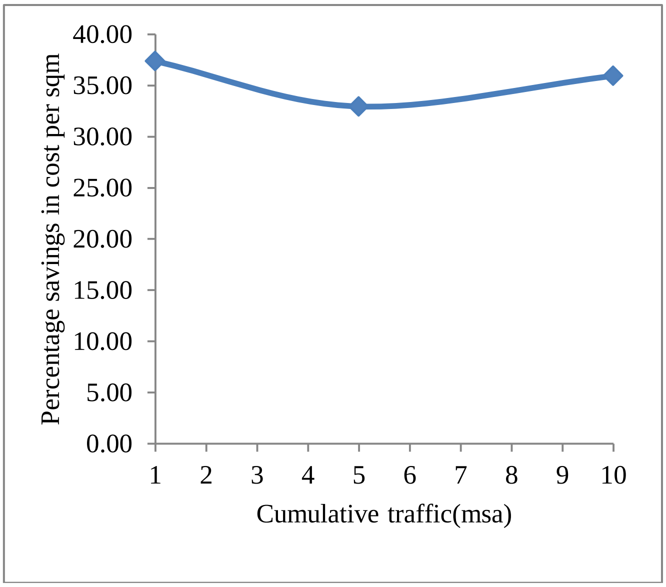

Figure (15): Variation of percentage savings in cost of pavement per m^2 with cumulative traffic

CONCLUSIONS

The conclusions drawn from this study are as follows:

1. The highest value of maximum dry density is achieved for 70% clay: 30% sand composite.
2. On increasing the sand content, the optimum moisture content of clay-sand mix decreases while the maximum dry density of clay-sand mix initially increases and then decreases on increasing the sand content.
3. The maximum dry density of clay-sand-fly ash mix decreases as the content of fly ash is increased while optimum moisture content shows a reverse trend.
4. The appropriate clay-sand-fly ash mix considered for further addition of tile waste and jute fiber is clay: sand: fly ash: 63%:27%:10%.
5. When tile waste is added to the selected appropriate clay-sand-fly ash mix, the maximum dry density increases up to a certain percentage of tile waste and then decreases.
6. On the inclusion of jute fiber in the optimum clay-sand-fly ash-tile waste mix, the maximum dry density increased slightly and then decreased with increasing jute fiber content. Addition of jute fiber does not affect the optimum moisture content appreciably.
7. The strength and permeability characteristics of clayey soil improved on addition of additives used in this study in the appropriate proportions.
8. Soaked and unsoaked CBR values improved considerably for the optimum mixes in comparison to that of locally available clayey soil.
9. The values of failure stress for the optimum mixes of composite materials are more than that of locally available clayey soil. The value of failure stress obtained for the final composite mix of clay-sand-fly ash-tile waste-jute fiber is not appreciably more than that of the pure clay, but considerable strain absorption capacity can be observed for this final composite mix.
10. The coefficient of permeability improves for optimum mixes of composite materials compared with that of locally available clayey soil.
11. The final optimum mix obtained is an improved construction material and when used in the construction of flexible pavement imparts considerable cost saving.

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