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Study on effective utilization of waste materials in the construction of pavements

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ABSTRACT

Research into new and innovative uses of waste material is continually advancing. Many highway agencies, a private organization, and individuals are in the process of a wide variety of studies and research projects concerning the feasibility, environmental suitability, and performance of using recycled products in highway construction. The amount of wastes has increased year by year and the disposal becomes a serious problem. Particularly, the recycling ratio of the plastic wastes in life and industry is very low and many of them have been reclaimed for the reason of unsuitable ones for incineration. It is necessary to utilize the wastes effectively with technical development in each field. Expansive soils are so widely spread that it becomes impossible to avoid them for highway construction to keep the network structure for mobility and accessibility. However, the roads constructed on expansive soils suffer extensive damage and distress resulting large economic losses running to billions of dollars. As thermal power plants are spatially distributed all over the country, utilization of flyash from these plants for the road construction, not only helps to consume bulk quantities of fly ash solving its disposal problem to a certain extent but also to satisfy the construction requirements. Reinforcement of soils with synthetic fibers is potentially an effective Technique for increasing soil strength. In recent years, this technique has been suggested for a variety of geotechnical applications ranging from retaining structure and earth embankments to subgrade stabilization beneath footings and pavements. Research on a different type of reinforcement and materials has been conducted by several investigators. However, the amount of information available on randomly oriented fiber reinforcement is still limited. Here an attempt is made to the suitability of different types of waste plastics strips and waste tyre rubber chips reinforcing with gravel and flash in flexible pavement system on expansive soil subgrade.

Keywords— *Flyash, Structure, Expansive Soil, Fiber Reinforcement, Subgrade, Synthetic Fibers, Plastics Strip, Footing*

1. INTRODUCTION

The amount of wastes has increased year by year and the disposal becomes a serious problem. The creation of nondecaying waste materials, combined with a growing consumer population, has resulted in a waste disposal crisis. One solution to this crisis lies in recycling waste into useful products. Research into new and innovative uses of waste materials is continually advancing. Many highway agencies. Private organizations and individuals have completed or are in the process of completing a wide variety of studies and research projects concerning the feasibility, environmental suitability, and performance of using recycled products in highway construction. Most developed and developing countries all over the world have huge resources of waste materials such as fly ash, stone dust, and waste plastic. The quantities of wastes that are accumulating in developed and developing countries are causing disposal problems that are both financially and environmentally expensive. One method to reduce some portion of the waste disposal problem is by utilizing these waste materials for engineering purpose.

In countries like India and Japan, the quality of coal is poor and they produce ash as much as 20-30% of their weight on burning. Coal in USA, UK, and Canada produce ash only about 10% of their weight (Sivapullaiah, 2001). Out of this huge quantity of flyash, hardly less than 5% is being put for gainful purposes like brick making, cement manufacture, void filling in tunnels, backfill, sludge stabilization, glass manufacture, agriculture, soil stabilization etc., (Hausmann, 1990; Singh and Murty, 1998; Suryanarayana, 2000), leaving a massive portion of the ash for storage in ash ponds. In spite of some inherent problems associated with flash utilization, the encouraging engineering properties of the material prompted engineering community to utilize it in bulk quantities for construction purpose, which not only helps to dispose of it but also to preserve the top fertile soil from using it for several purposes. A number of studies have been made on the physical and engineering properties of coal ashes (Pandian et al., (1998), Sridharan et al., (1996, 1999) Srinivasa Rao et al., (1998) and their utilization in geotechnical engineering practice (Leonards and Bailey (1982), Toth et al., (1988)).

2. REVIEW OF LITERATURE

India has diverse geographical regions with different terrains, climate, rainfall, traffic pattern and availability of construction materials coupled with a wide range of soil types. Therefore, a standard method of design or a uniform technique of construction cannot hold good to meet the requirements of all areas and this calls for the adoption of appropriate design and different technologies based on area-specific conditions. Technological innovations like the use of enzymes for ground improvement, waste plastics strips and waste tyre chips, blended bitumen, composite pavement technique etc. Can be gainfully tried for cost-effective construction. Studies have revealed that a substantial economy to the tune of 20% and more can be achieved by using these materials and by introducing innovative technologies. It is a well-known fact that the naturally occurring materials are fast depleting because of their over exploitation to meet the huge demand for construction of infrastructure projects. To cope with the huge demand of these materials at present and in the future, sufficient reserves have to be ensured and these reserves are non-replenishable. Unless we fulfill this task now, the existing reserves of natural resources of materials will ultimately disappear for which the next generation will not pardon us. Besides, the amount of energy consumed for blasting the hills for quarrying operations, crushing the rocks, transportation of this material to plants, mixing, laying etc is doing unspeakable damage to the environment. On the other hand, locally occurring materials like soil, gravel, moorum, laterite, sand, and emerging materials like mine waste, industrial slag, jute geo-textile, soil-enzymes, etc. can be effectively used singly or in combination with other materials as an alternative to conventional materials, with significant economy after studying their physical and engineering properties for their suitability in road construction. There may be situations where the existing pavements have to be dismantled. In such cases, the dismantled materials can be considered for re-use by recycling, duly supplemented with fresh materials compatible with dismantled materials. In recent times, a technology referred to as aggregate-free technology has come into use, where several environment-friendly enzymes are used for improving the engineering properties of soils to minimize or almost eliminate the use of aggregates. Such materials can be tried for roads, if found suitable in Indian conditions, through field trials. Trials can at least begin on roads of lesser importance which aggregate to a larger portion of the total road network. Use of waste plastic in bitumen has revealed improved performance, stability, strength and fatigue life, reduction in overall rutting and low-temperature cracking of the bituminous surfacing. For ground improvement in areas of low bearing capacity soils, marshy land and locations with drainage problems use of geo-textiles, jute or coir is a proven technology to render positive results and cost-effectiveness especially in rural roads. In the north-eastern region, the soft soils, as well as non-availability of aggregates, pose difficulties for road construction. There is, therefore, a need to improve these materials. There are techniques to improve the quality of local materials. To use new materials, improved construction techniques are being practiced the world over. The reinforced earth construction, use of geo-textiles, improved drainage systems, advanced technique/technology etc are some of the techniques which can be used.

Table 1: Physical and chemical properties of flyash

S. no	Description	Observed Values
1	Specific Gravity	1.90 – 2.50
2	Plasticity	N.P*
3	Maximum dry density	0.95 – 1.60 gm/cm^3
4	Optimum moisture content (OMC)	19% - 38%
5	Permeability	8x10^{-6} to 7x10^{-4} cm/sec
6	Uniformity	3.0 – 10.5
7	Compression index (Cu)	0.05 – 0.40
8	Cohesion (C)	Negligible
9	The angle of shearing resistance	30 – 40
10	Coefficient of consolidation	1.75x10^{-5}to 2.00x10^{-3} m^2/sec
11	Silica (SiO_2)	46.50 (%)
12	Alumina (Al_2O_3)	24.20 (%)
13	Iron (Fe_2O_3)	10.00 (%)
14	Calcium (CaO)	13.00 (%)
15	Magnesium (MgO)	4.00 (%)
16	Sulphur Content (SO_3)	Traces
17	Carbon	1.10 (%)

3. METHODOLOGY

Various tests are carried out in the laboratory for finding the index and other important properties of the soils used during the study. Direct shear and CBR tests were conducted by using different percentages of waste tyre rubber chips and waste plastics strips are mixed with gravel and flash materials for finding the optimum percentage of waste tyre rubber chips and waste plastics strips. Cyclic load tests and heave measurements are carried out on the flexible pavements prepared in a circular steel tank. The details of these tests are given in the following sections.

3.1. Index Properties

The standard procedure recommended in the respective I.S Code of practice has been followed while finding the Index properties viz. Liquid Limit, Plastic Limit and Shrinkage Limit of the samples tried in this investigation.

3.1.1. Direct shear tests: The direct shear test was conducted in the laboratory as per IS Code as shown in Plate No. 3.3. Different percentage of waste tyre rubber and waste plastics strips by dry unit weight of soil were mixed uniformly with the soil. The water content corresponding to OMC of untreated soil was added to the soil in small increments and mixed by hand until uniform mixing of the strips was ensured. The soil was compacted to maximum dry density (MDD) of untreated soil. The specimens were tested in a 6cm x 6cm x 2cm square box at normal plastics strips with gravel and flyash and sheared at a rate of

1.25 mm/min. the graph was plotted between normal stress and shear stress at failure for each percentage of waste tyre rubber and waste plastics strips for obtaining the shear strength parameters.

3.1.2. California Bearing Ratio (CBR) Tests: The California Bearing Ratio (CBR) tests were conducted in the laboratory by using a standard California Bearing Ratio (CBR) testing machine. According to IS 2720 (part 16) 1979. Different samples are prepared in the similar lines for CBR test using gravel and flyash material reinforced with waste tyre rubber chips and waste plastics strips and the details of which are given in table 2 and in the Plate No. 3.4.

Table 2: Different percentages of reinforcing materials

Type of Sub-base Material	Reinforcing Material	Di Percentages of Reinforcing material (% by Dry Unit Weight of Soil)
Gravel	WP + WTR	(0.0+0.0), (0.1+1.0), (0.2+2.0), (0.3+3.0)
Flyash	WP + WTR	(0.0+0.0), (0.1+1.0), (0.2+2.0), (0.3+3.0)

Optimum percentage of waste tyre rubber and waste plastics strips for gravel/flyash material, based on direct shear and CBR tests are obtained and the studies are extended using 60cm diameter Mild Steel Tank, the details of which are given in Plate No. 3.5.

3.1.3. Construction of model flexible pavement: In this investigation, eight model flexible pavements are prepared in the laboratory by using 60cm diameter mild steel tank with and without reinforcement materials. Expansive soil is used as a subgrade soil, Gravel and flyash as subbase course are laid uniformly for all the tests. Details of the procedures followed in the construction of model flexible pavements are given in the following sections.

3.1.4. Construction procedure of model flexible pavement on expansive subgrade preparation of subgrade: The expansive soil brought from Amalapuram is allowed to dry and then pulverized to small pieces with Steel rammers and sieved through 4.75mm sieve. Then it is compacted to a 2.0cm thickness in 10 layers to a total thickness of 20cm to its optimum moisture content and maximum dry density in the mild steel test tank.

3.1.5. Preparation of sub base: On the prepared subgrade, gravel / flyash subbase material mixed with water at OMC is laid in two layers each of 2.5cm compacted to a total thickness of 5.0cm. The subbase layer is compacted corresponding to MDD and OMC, in which, gravel/flyash subbase materials are mixed with optimum percentage of waste tyre rubber chips and waste plastics strips obtained from laboratory direct shear and CBR test results, thoroughly and spread in two layers to a total compacted thickness of 5.0cm. These layers are also compacted to optimum moisture content and maximum dry density.

3.2. Testing on model flexible pavement

The following tests were carried out on the prepared model tanks is to assess the efficiency of reinforcement in improving the overall performance in comparison with the controlled model pavement.

3.2.1. Heave Measurements: The model flexible pavement system is saturated completely by pouring water above the base course. Heave reading is taken with the help of dial gauges at regular intervals for the expansive soil subgrade pavements as shown in the Plate No.3.6. These readings are measured until there is no significant change between consecutive readings observed.

3.2.2. Cyclic Load Tests on Model Pavements: These tests are carried out on a flexible pavement system in a circular steel tank of diameter 600mm as shown in Plate No. 3.5 & 3.6. The loading is done through a circular metal plate of 100mm diameter laid on flexible pavement system. The steel tank is placed on the pedestal of the compression testing machine. A five-ton capacity proving ring is connected to the loading frame and the extension rod welded to the circular plate is brought in contact with proving ring, two dial gauges of least count 0.01mm are placed on the metal flats welded to the vertical rod to measure the vertical displacements of the loading plate. The load is applied in increments corresponding to tyre pressures of 100, 200, 300, 700 and 1000 kPa and each pressure increment is applied cyclically until there is an insignificant increase in the settlement of the plate between successive cycles. The testing is further continued until the occurrences of failure to record the ultimate loads.

3.3. Summary

The properties of materials used and the experimental procedures followed during the laboratory experimentation are discussed in this chapter. The results of the laboratory and field tests will be discussed in the following chapter.

4. RESULTS AMD DISCUSSIONS

4.1 Compaction tests results

I. S. Heavy compaction tests are conducted as per IS: 2720 (Part VIII) in the laboratory tested by using for Gravel and flyash materials with varying percentage of reinforcing materials waste tyre rubber and waste plastics strips and the results and graphs from these tests are furnished in table 3 and figure 1,2,3,4.

Table 3: Compaction parameters for gravel and flyash material reinforced with different percentages of waste plastics and waste tyre rubber

% of WP + WTR	Gravel		Flyash	
	OMC %	MDD "kN/m^3"	OMC %	MDD "kN/m^3"
0.0+0.0	14.2	18.2	13.57	13.76
0.1+1.0	15.33	19.4	14.59	14.02
0.2+2.0	16.44	19.52	15.10	14.79
0.3+3.0	16.27	18.8	15.68	15.08
0.4+4.0	-	-	16.71	14.39

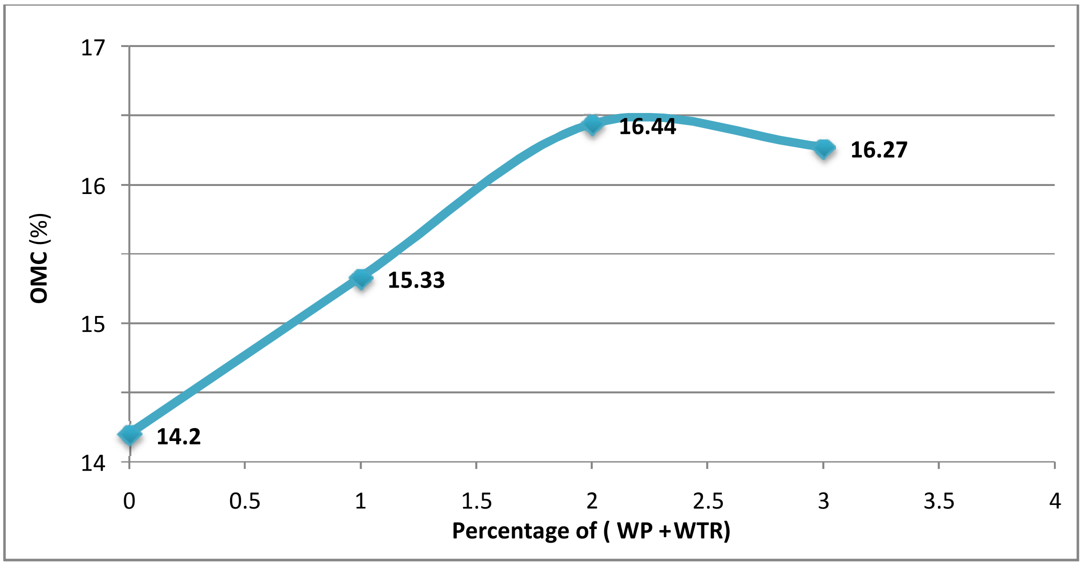

Fig. 1: Variation of optimum Moisture Contant (OMC) for gravel material reinforced with different percentages of waste plastics strips and waste tyre rubber chips

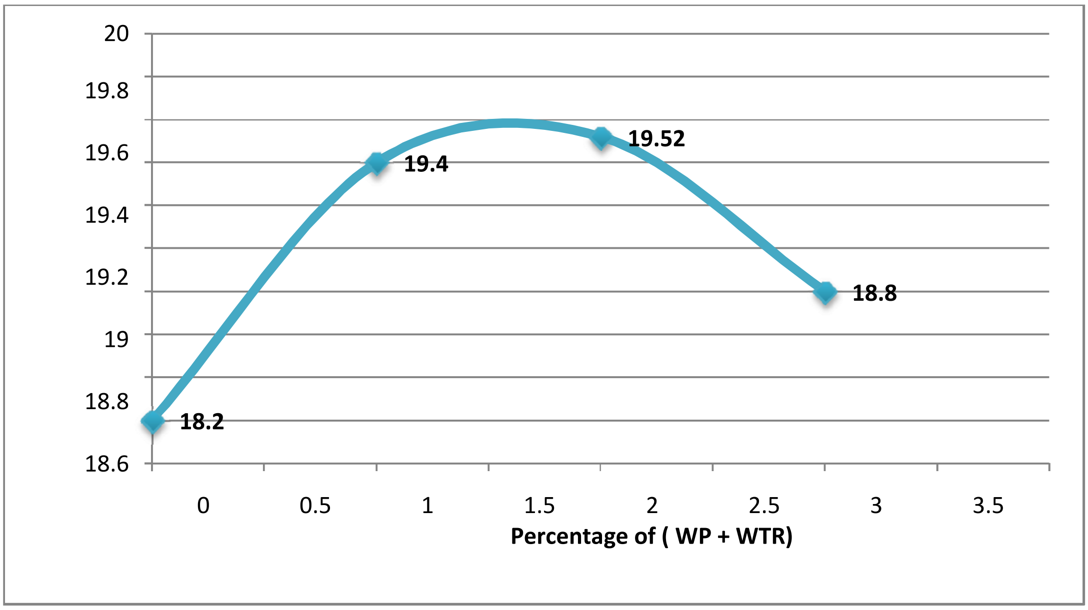

Fig. 2: Variation of Maximum Dry Density (MDD) for gravel material reinforced with different percentages of waste plastics strips and waste tyre rubber chips

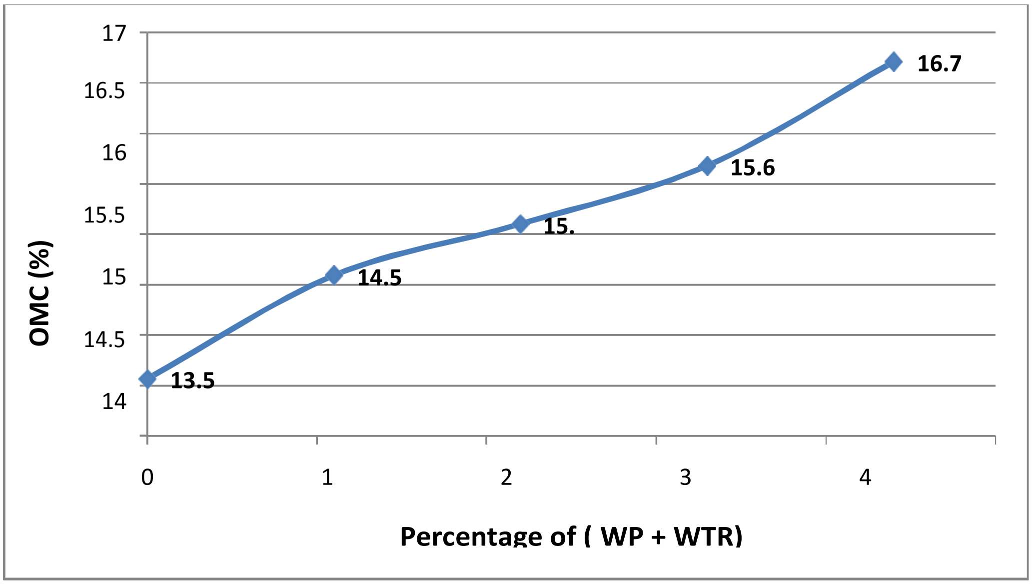

Fig. 3: Variation of optimum moisture contant (OMC) for flyash material reinforced with different percentages of waste plastics strips and waste tyre rubber chips

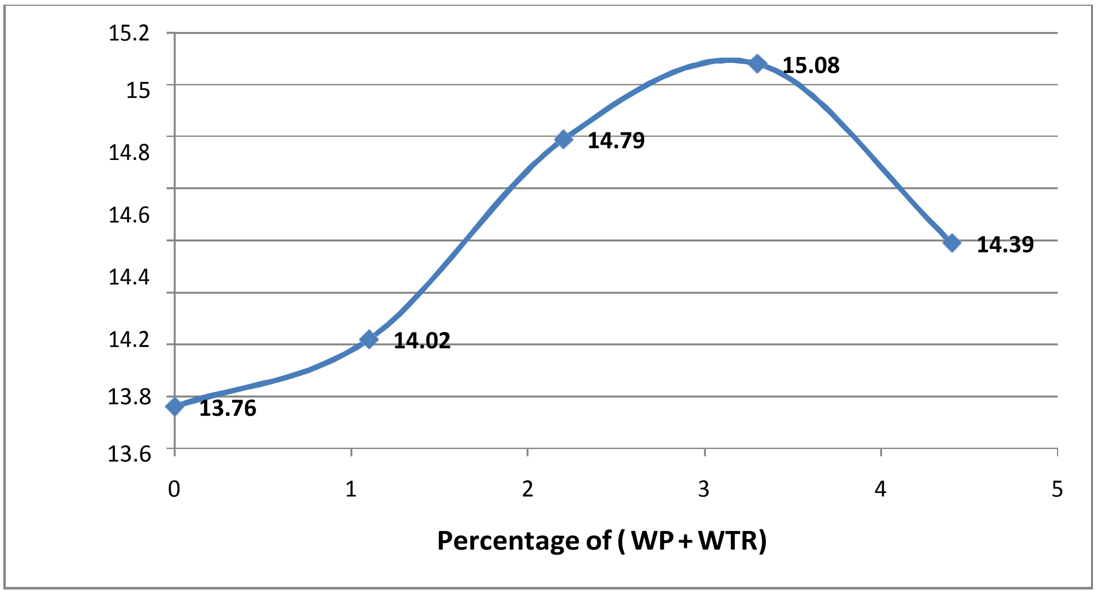

Fig. 4: Variation of Maximum Dry Density (MDD) for flyash material reinforced with different percentages of waste plastics strips and waste tyre rubber chips

Based on above compaction results of both gravel and flyash as the percentage of reinforcing materials increases, the maximum dry density increases and optimum moisture content increases for gravel upto (0.2% of WP+2.0% of WTR), similarly for flyash upto (0.3% of WP+3.0% of WTR). Further addition of reinforcing material the maximum dry density decreases (table 3). Graphs are drawn between water content and dry density for each percentage, from these results optimum moisture content and maximum dry density values arrive. The results and graphs from these tests are shown in figure 1,2,3,4.

4.2 Direct Shear Test Results

The direct shear tests were conducted as per IS:2720 (part XIII, 1986) in the laboratory for gravel and flyash materials with and without waste tyre rubber and waste plastics strips and the results are furnished in table 4, figures 5,6,7,8. The Specimens are tested by using the direct shear testing machine for gravel and flyash materials mixed with varying percentages of waste tyre rubber chips and waste plastics strips. Graphs drawn between normal stress and shear stress for each percentage, from these shear strength parameters such as Angle of internal friction and cohesion values are calculated.

Table 4: Shear strength parameters for gravel and flyash material reinforced with different percentages of waste plastics and waste tyre rubber

% of WP+WTR	Gravel		Flyash	
	Cohesion (kN/m^2)	Angle of Internal Friction ($Ø^0$)	Cohesion (kN/m^2)	Angle of Internal Friction ($Ø^0$)
0.0+0.0	0.6	38	1	26.33
0.1+1.0	1.1	37	1.5	27.57
0.2+2.0	1.6	36	2.5	28.48
0.3+3.0	1.8	36	3.2	29.3
0.4+4.0	-	-	3.1	29.3

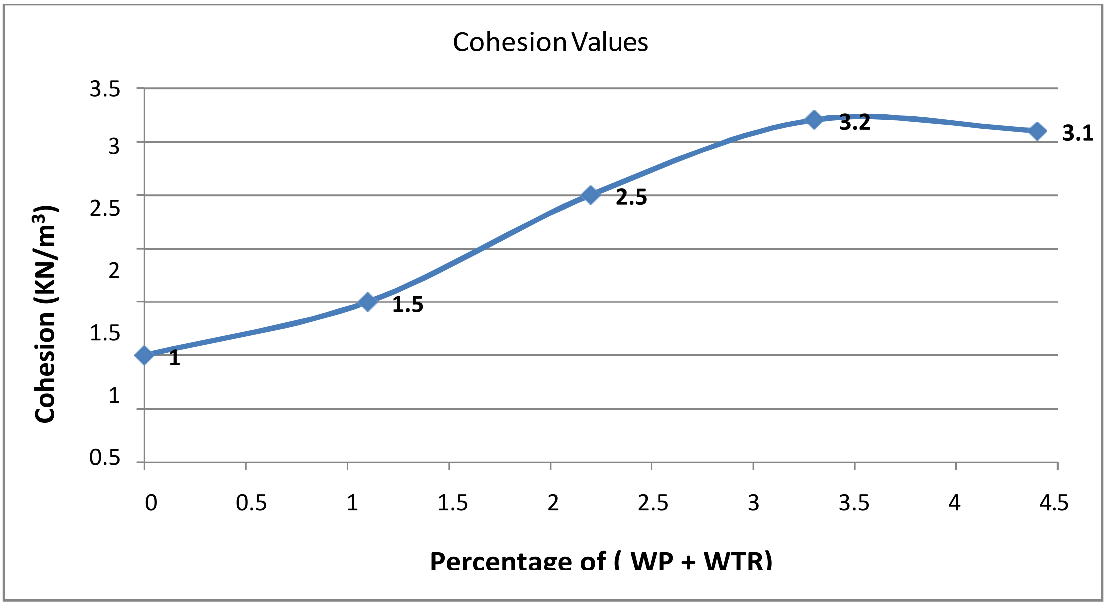

Fig. 5: Variation of cohesion values for gravel material reinforced with different percentages of waste plastics strips and waste tyre rubber chips

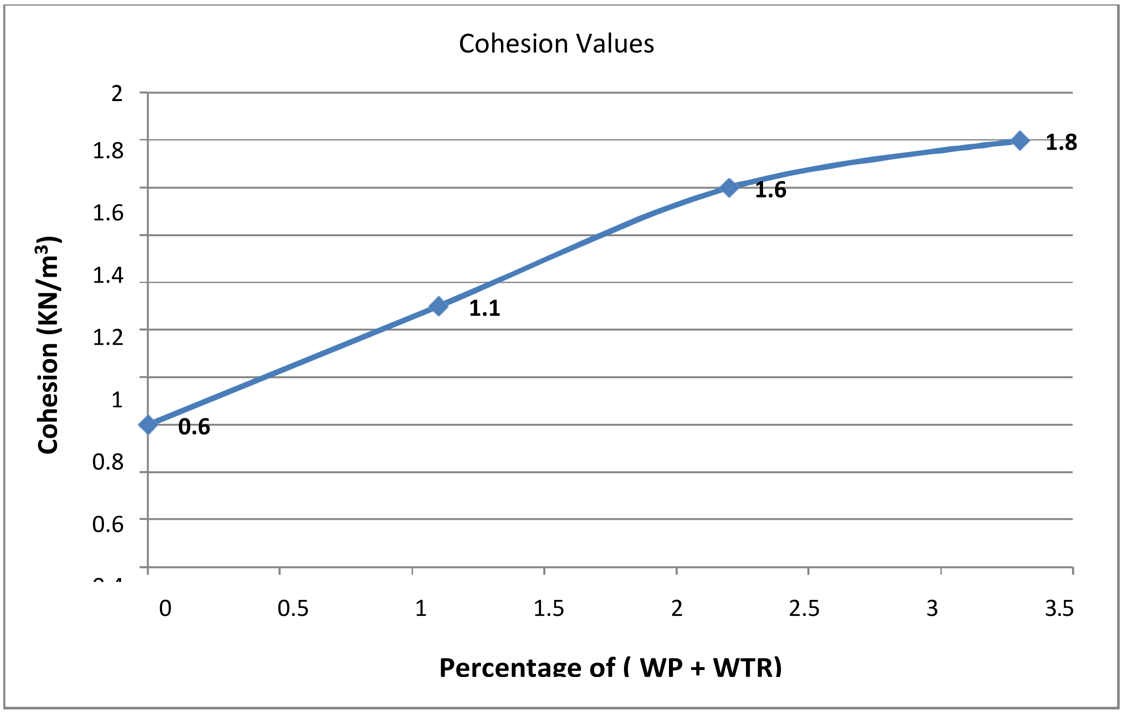

Fig. 6: Variation of cohesion values for flyash material reinforced with different percentages of waste plastics strips and waste tyre rubber chips

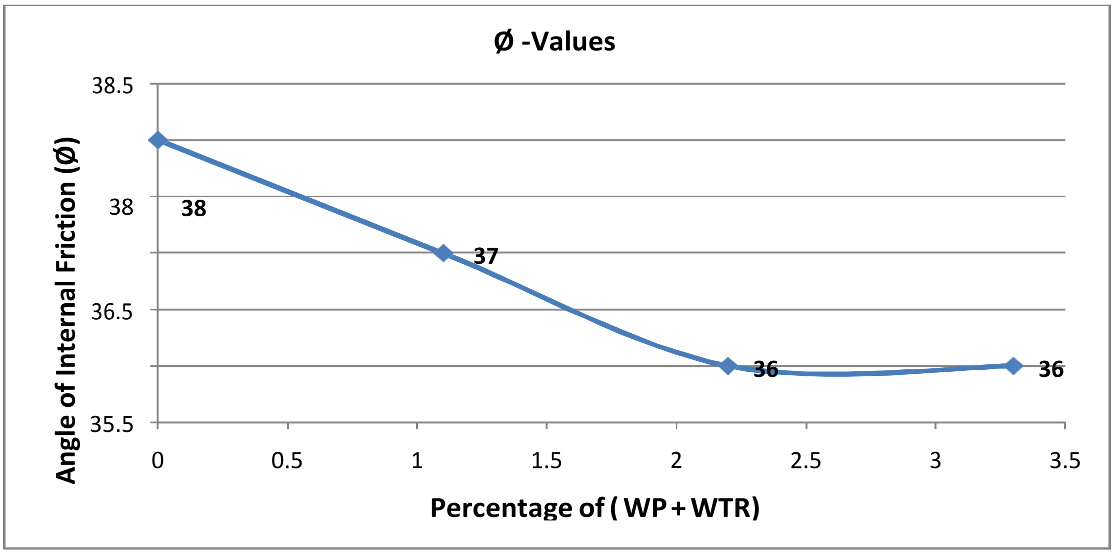

Fig. 7: Variation of angle of internal friction values for gravel material reinforced with different percentages of waste plastics strips and waste tyre rubber chips

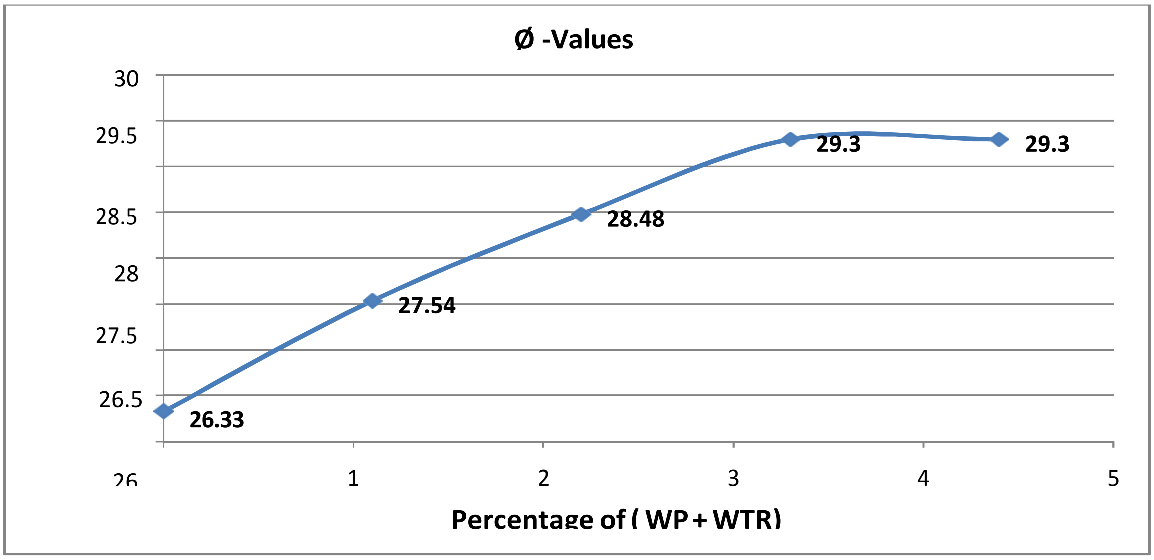

Fig. 8: Variation of angle of internal friction values for flyash material reinforced with different percentages of waste plastics strips and waste tyre rubber chips

Based on the above results, it is observed that for gravel reinforced with waste plastic strips and waste tyre rubber chips, the angle of internal friction values are decreased from 38^0 to 36^0 with (0.2% of WP +2.0% of WTR), similarly for flyash the angle of internal friction value increases from 26.33^0 to 29.3^0 with (0.3% of WP + 3.0% WTR) and the cohesion values are increased for gravel from 0.6 to 1.6kN/m^2 with (0.2% of WP +2.0% of WTR), similarly for flyash from 1 to 3.2kN/m^2 with (0.3% of WP and 3.0% of WTR) and further addition of waste plastics strips and waste tyre rubber does not affect the angle of internal friction and cohesion, as shown in figure 5,6,7,8.

4.3 California Bearing Ratio (CBR) test results

The California Bearing Ratio (CBR) tests were conducted in the laboratory by using a standard California Bearing Ratio (CBR) testing machine according to IS: 2720 (part16) 1979. Samples are prepared for CBR test for flyash materials with and without waste tyre rubber chips. The results are given in table 5 and graphs (figures) 9 and 10.

Table 5: Variation of soaked CBR values for gravel and flyash materials reinforced with different percentages of waste plastics and waste tyre rubber

% of WP + WTR	Gravel	Flyash
	Soaked CBR (%)	Soaked CBR (%)
0.0+0.0	6.13	4.13
0.1+1.0	6.9	5.85
0.2+2.0	8.25	6.96
0.3+3.0	7.6	7.82
0.4+4.0	-	6.86

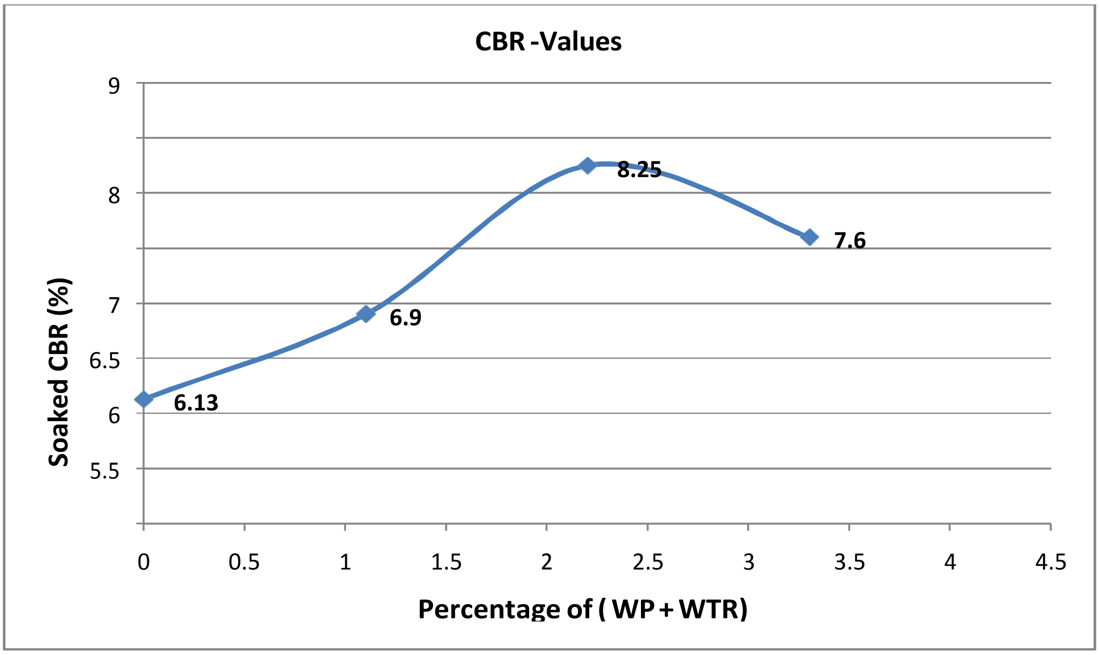

Fig. 9: Variation of Soaked CBR values for gravel material reinforced with different percentages of waste plastics strips and waste tyre rubber chips

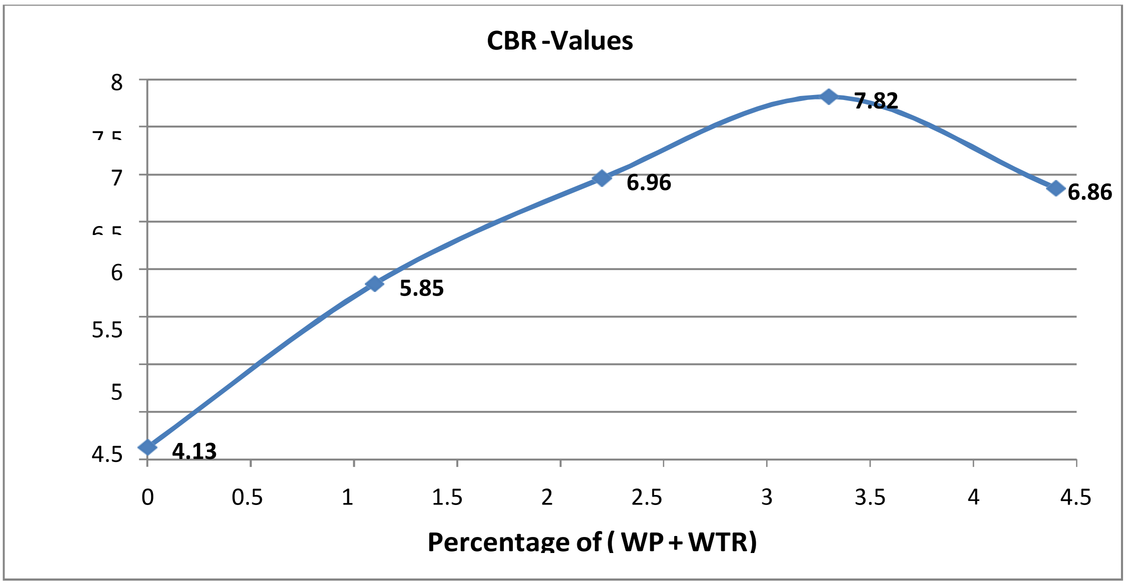

Fig. 10: Variation of Soaked CBR values for flyash material reinforced with different percentages of waste plastics strips and waste

Tyre Rubber chips

It is observed from the results, that for gravel reinforced with waste plastics strips and waste tyre rubber chips, soaked CBR values for gravel are increased from 6.13 to 8.25 with (0.2% of WP+ 2.0% of WTR), similarly for flyash CBR values increased from 4.13 to 7.82 for (0.3% of WP + 3.0% of WTR) further addition of (WP+WTR) does not affect the CBR value.

From the results of compaction, direct shear, and California Bearing Ratio Tests, the optimum percentage for gravel material is (0.2% of WP + 2.0% of WTR), similarly for flyash is (0.3% of WP+3.0% of WTR).

5. LABORATORY PAVEMENT STUDIES

To know the relative performance of waste plastics strips and waste tyre rubber chips strips reinforcement material, model flexible pavements are prepared on expansive soil subgrade with gravel and flyash as subbase material in the laboratory. Heave measurements and plate load tests were conducted on the laboratory model flexible pavements and the results of which are discussed in the following article.

5.1 Heave Measurements

The heave measurements were taken for different time intervals for all the alternatives of model flexible pavements in the laboratory. The heave vs. time graphs for different reinforcing materials used in subbase of model flexible pavement system are presented in tables 6 and table 7 and figure 11, 12.

Table 6: Heave– Time Plot for different model flexible pavements laid on expansive soil subgrade with gravel subbase

Time (Hours)	Heave (mm)	
	Gravel	WTR+WP
0.000	0	0
0.017	0.04	0.03
0.050	0.05	0.04
0.084	0.0	0.055
0.117	0.06	0.0625
0.150	0.07	0.0725
0.200	0.085	0.0825
0.267	0.1	0.1025
0.400	0.24	0.16
0.467	0.255	0.1775
0.583	0.31	0.195
0.600	0.36	0.225
0.750	0. 38	02725
1.000	0.48	0.3
1.500	0.54	0.3725
2.000	0.75	0.4325
3.000	0.85	0.6
22.000	3.01	2.21
23.000	3.17	2.34
24.000	3.25	2.44
25.000	3.42	2.58
32.700	4.84	3.94
36.500	4.91	4.2
41.900	5.14	4.7
51.000	7.05	6.015
70.000	7.35	6.72
72.000	7.5	6.92
75.000	7.6	60935
94.000	7.8	6.7375
96.000	7.85	6.79
105.000	7.92	7.14
110.000	8.02	7.235
120.000	8.1	7.375

Table 7: Heave- Time plot for different model flexible pavements laid on expansive soil subgrade with flyash subbase

Time (Hours)	Heave (mm)	
	Gravel	WTR+WP
0.000	0	0
0.017	0.05	0.1775
0.050	0.08	0.065
0.084	0.1	0.0865
0.117	0.12	0.137

0.150	0.15	0.1725
0.200	0.31	0.325
0.267	0.43	0.36
0.400	0.65	0.495
0.467	0.78	0.675
0.583	0.83	0.795
0.600	1.03	0.855
0.750	1.05	0.9
1.000	1.29	1.196
1.500	1.58	1.32
2.000	1.28	1.59
3.000	2.06	1.66
22.000	2.48	1.75
23.000	2.88	2.09
24.000	3.38	2.555
25.000	4.04	3.225
32.700	4.87	4.775
36.500	5.27	5.52
41.900	6.2	5.95
51.000	6.49	6.68
70.000	7.93	6.885
72.000	8.15	7.055
75.000	8.4	8.135
94.000	8.63	8.7
96.000	8.71	8.9
105.000	8.92	9.195
110.000	9.03	9.28
120.000	9.13	9.535

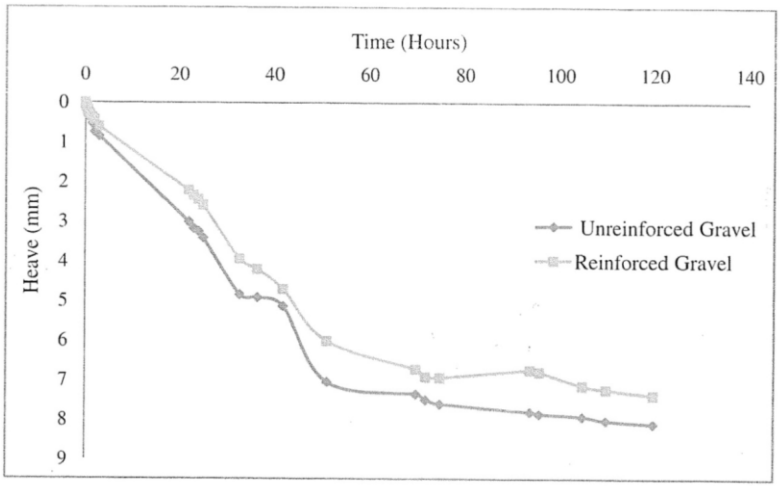

Fig. 11: Laboratory heave-Time plot for waste tyre rubber chips reinforced model flexible pavements laid on expansive solid subgrade with gravel subbase

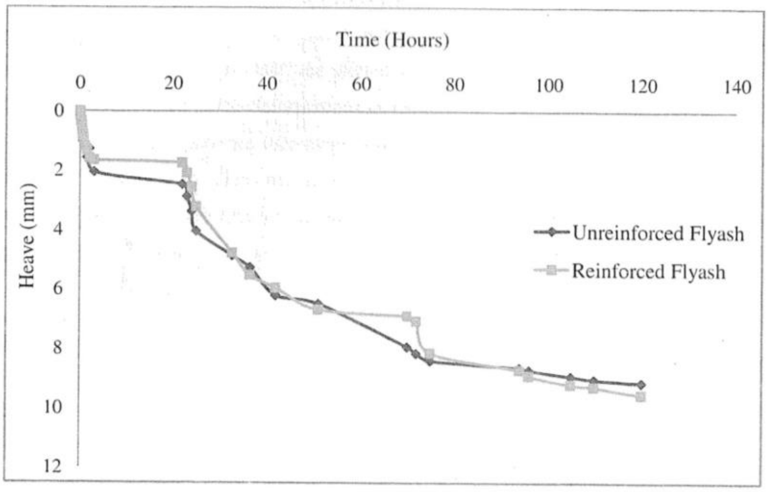

Fig. 11: Laboratory heave-Time plot for waste tyre rubber chips reinforced model flexible pavements laid on expansive solid subgrade with flyash subbase

Table 8: Pressure-deformation values for different reinforcement materials in gravel subbase of flexible pavement system laid on expansive soil subgrade (Tested at unsaturated state)

Pressure (kPa)	Gravel Reinforced with WP + WTR		Unreinforced Gravel	
	Total Deformation (mm)	Elastic Deformation (mm)	Total Deformation (mm)	Elastic Deformation (mm)
0	0	0	0	0
100	0.2	0.1	0.35	0.31
200	0.5	0.2	1	0.56
300	1.02	0.405	1.52	0.85
400	1.58	0.524	2.275	1.06
500	2.365	0.645	2.85	1.275
600	3.47	1.57	4.15	2.975
700	4.9	2.2	-	-
800	8.15	3.5	-	-

Table 9: Pressure-deformation values for different reinforcement materials in flyash subbase of flexible pavement system laid on expansive soil subgrade (Tested at unsaturated state)

Pressure (kPa)	Gravel Reinforced with WP + WTR		Unreinforced Gravel	
	Total Deformation (mm)	Elastic Deformation (mm)	Total Deformation (mm)	Elastic Deformation (mm)
0	0	0	0	0
100	0.515	0.34	0.87	0.65
200	1.12	0.67	1.71	0.91
300	1.64	0.91	1.98	1.28
400	2.58	1.18	3.2	1.54
500	3.01	1.34	3.7	2
600	4.8	3.57	-	-
700	6.4	4.36	-	-

5. CONCLUSIONS

On the whole, this study has attempted to provide an insight into the compaction, direct shear and CBR behavior of gravel and flyash reinforced with waste plastics and waste tyre rubber. Utilizing some portion of the waste in this way will reduce the quantity of waste requiring disposal. More so the disposal in this way will be in an environmentally friendly manner. The study yielded the following conclusions based on the laboratory experimentation carried out in this investigation.

- Addition of (waste plastics + waste tyre rubber) inclusions in gravel and flyash results in an appreciable increase in the shear characteristics and CBR value.
- From the result of direct shear and CBR tests, gravel and flyash reinforced with different percentage of (waste plastics + waste tyre rubber), for gravel the optimum percentage of waste plastic strips and waste tyre rubber is equal to (0.2+2.0) % of dry unit weight of soil, similarly for flyash it is equal to (03+3.0)% of dry unit weight of soil. The addition of (waste plastics + waste tyre rubber), beyond (0.2+2.0) % does not improve the strength characteristic values for gravel and similarly for flyash beyond (0.3+3.0)% does not improve the strength characteristic values appreciably.
- No significant control of heave is observed when reinforcement is placed in flexible pavement subbase laid on expansive soil subgrade.
- The total and elastic deformation values of flyash the flexible pavement system are increased is when compared to gravel by the provision of the (waste plastics + waster tyre rubber), reinforcement laid on expansive soil subgrade, in comparison with the conventional flexible pavement system.
- The total carrying capacity of the laboratory model flexible pavement system is significantly increased by introducing (waste plastics + waster tyre rubber) reinforcement material in gravel and flyash subbase laid on expansive soil subgrade.
- The maximum load carrying capacity followed by less value of rebound deflection is obtained for waste plastic strips and waste tyre rubber reinforced stretch laid on the flexible pavement system.

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