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Utilization of Pond Ash Combined with Polypropylene Fiber in Highway Embankment

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ABSTRACT

Coal generates most energy in India. Coal waste disposal causes environmental issues. Highway embankments, concrete pipes, pavements, bridges, and dams can utilize this waste. It can be used as subgrade for roads. Since coal ash is less dense than typical soil, it may be utilised in highway embankments if strengthened adequately. Coal ash needs admixtures or reinforcement to improve its properties. Due to abundant low-cost synthetic materials, reinforcing geomaterials is popular. Pond ash (PA) was improved geotechnically by adding polypropylene fibre (PF) from waste plastic weaved bags. For aspect ratio (AR) 50, 100, and 150, PF by dry PA weight was varied from 0-2% at 0.5% intervals. At 100 AR, PF reinforcement increased maximum dry density by 16%. Adding 2% PF to PA at 100 aspect ratio reduces optimal moisture content by about 9%. At an AR of 100, adding 1.5% fibre to Pond ash increased CBR by 46%. Thus, these two waste products can be used as subgrade. Using pond ash as a reinforcement enhances the CBR value, which in turn permits a thinner pavement. Pond ash with 1.5% fibre content at an aspect ratio of 100 had the highest cohesion and effective friction angle of all the compositions tested in a direct shear test. Geo-studio (2021) slope-analysed this composition's direct shear test results. Geo Studio models were constructed at 1V: 2H and 1V: 1.5H slopes for embankments along three different heights of highways (10 m, 20 m, and 30 m) to test for stability.
Keywords: Pond Ash, polypropylene fiber, CBR, highway embankment.

1. INTRODUCTION

Most electricity comes from thermal power plants, and coal is the primary fuel utilised worldwide. When compared to hydro power (46.2 GW) and nuclear power (6.7 GW), India's 267 thermal power plants' production of 234.7 GW is enormous (CEA, 2021). This results in huge generation of coal and generates a lot of ash as by-product. All thermal power plants dump coal ash into nearby low-lying regions which are called ash ponds. These ash ponds have already taken up 65,000 acres of valuable land in India (Mohanty and Patra, 2015). The ash content of Indian coal ranges from 35 to 45 percent, resulting in considerable production in terms of volumes of pond ash (Kumar, 2009). In a nation with such a high population density as India, the transformation of valuable land into landfills for ash disposal presents difficulties for agricultural productivity and habitat. Fly ash and pond ash, both relatively lightweight construction materials, have recently gained attention for their potential usage in highway embankments and other applications. Despite the fact that pond ash is used in a number of ways, it accounts for around 70 percent of all ash generated by weight, with 25% going to the cement industry and the rest going to Bricks & Tiles, Ash Dyke Raising, mine filling, Reclamation of low-lying areas, Roads and Flyovers, and so on, leaving one-third ash unused (CEA, 2021).

Reinforcing these materials using different types of lightweight fibres in different quantities may stabilise the material and improve attributes like shear strength, modulus of elasticity, resilient modulus, etc. The use of various waste products in highway embankment construction have received attention in recent years due to the scarcity and high cost of materials used. Randomly distributed fibres reinforced soil (RDFS) is a recent ground improvement approach that includes adding a certain kind and number of fibres to the soil, mixing them in a random pattern, and then compacting them in place. Using fibres that are dispersed at random has a number of advantages, including the following: Improvements in shear strength are accomplished while isotropic and residual strength continues to be maintained. It is possible to increase ductility and seismic performance (Chauhan et al., 2008; Malik and Singh, 2020). However, pond ash needs an admixture before it may be used to replace sand in highway embankment. As a result, polypropylene fibre (PF) reinforcement was used to modify the behaviour of pond ash. The effect of fiber-reinforcing features of compacted mixes was investigated using a series of tests which included CBR, direct shear strength and UCS of mix compositions in order to use it as a subgrade material. The aspect ratio of a soil specimen is defined as the ratio of its height to its diameter. The significance of aspect ratio in the strength of subgrade material lies in the fact that it affects the stress distribution within the soil sample during loading. When a soil sample is subjected to a compressive load, the stress distribution within the sample depends on its aspect ratio. A high aspect ratio sample will experience more stress concentration at the edges, leading to a higher probability of failure at those locations. On the other hand, a low aspect ratio sample will experience more uniform stress distribution, resulting in a more evenly distributed failure pattern. Several researchers (Tang et al., 2007; Kumar and Singh, 2008; Sultana et al., 2013; Maurya et al., 2015) have used coconut coir, polypropylene fibre, glass fiber etc. as a reinforcing agent in their local soil and concrete to provide strength but the study on behaviour of polypropylene fibre in pond ash with different aspect ratio as a subgrade material in design of highways was yet to be studied.

2. EXPERIMENTAL PLAN

The experimental work was carried out in the Soil Mechanics Laboratory of Punjab Engineering College, Chandigarh, India. The experimental study was aimed at finding out the feasibility of using pond ash with polypropylene fiber for use of composite material in subgrade of the pavement. Pond ash, the primary material in the study, was collected from Guru Gobind Singh Super Thermal Power Plant and the admixture polypropylene fiber is readily available and added in different percentage by weight. Weight of polypropylene fiber was taken after a review of literature with varying percentage of fiber as 0, 0.5, 1, 1.5 and 2 respectively (Mishra et al., 2016; Mogili et al., 2020). After fixing the percentage of PF in pond ash, experimental program was carried out. The experiments included Specific gravity of pond ash, Grain size analysis of pond ash for soil classification, Static Cone penetrometer test, Modified Proctor test for optimal moisture content (OMC) and maximum dry density (MDD), Unconfined compression test, California bearing ratio (CBR) test for finding out the suitability of material to be used as sub-grade/sub-base, Direct shear test for shear strength parameters. Specific gravity test has been performed as per IS: 2720 (Part-III): 1980 was used to calculate the specific gravity of pond ash. The liquid limit of the soil sample is determined by two methods Casagrande's method (IS: 9259:1979) and by cone penetrometer method (IS:2720 (Part-V):1985), mostly liquid limit of the clayey soil sample is easily obtained by Casagrande's apparatus, since our sample is pond ash that comes under the category of silty sand cannot be determined by Casagrande's apparatus hence liquid limit is determined by cone penetrometer method. For coarser particles, sieve analysis was used while hydrometer analysis was used for finer particles as per IS: 2720 (Part-IV): 1985. The moisture content and dry density relationships were determined using the modified proctor test, as per IS: 2720 (Part-VIII): 1980. Heavy compaction involves applying a greater amount of energy to the soil sample, typically through a higher number of blows from a heavier hammer, in order to achieve a higher degree of compaction. This can result in a denser, more uniform soil sample with greater resistance to deformation and higher load-bearing capacity. To test the application of pond ash in subgrade and sub-base for mild compaction and light traffic, a number of California bearing ratio tests were performed as per IS 2720 (Part-XVI): 1987.

For the test, cylindrical specimens having an internal diameter of 150 mm and a height of 175 mm at maximum dry density (MDD) were created in a metallic cylinder mould. A mechanical loading machine with a moving base that moves at a regular pace of 1.25 mm/min and a calibrated proving ring was used to readjust the proving ring. Cylindrical specimens corresponding to their MDD were formed for UCS in a metallic split mould with dimensions of 3.8 cm (dia.) 7.6 cm (height) at OMC as per IS 2720 (Part-X): 1991. These specimens were subjected to compression testing at a rate of 1.25 percent per minute until a reversal of dial gauge of load was detected or 20 percent strain in height was recorded, whichever occurred first. Stress vs strain curves were used to determine the specimen's unconfined compressive strengths. The unconfined compressive strength of the pond ash specimens reinforced with an aspect ratio 50,100 and 150 with size of fibers varying from 15 to 50 mm in length was determined for specimens with different percentage of fiber (i.e., 0.5%, 1%, 1.5%, and 2%). The composition of mixed samples is indicated by the code $PAxxPF_{yy}$, where xx represents the proportion of polypropylene fiber in percentage w.r.t. total weight of the sample and yy represents the aspect ratio.

3. MATERIALS AND METHODS

The two materials used in the current study are pond ash and polypropylene fiber. To use the two materials in road construction the strength and geotechnical properties of pond ash and pond ash – fiber mix (PA-PF) in subgrade and sub-base of pavement needs to be evaluated. The PA sample has a specific gravity of 2.11, while the specific gravity of the polypropylene fiber is 0.92. The plastic limit test was performed on the sample but pond ash failed to roll into threads shape formation because of very low cohesion and low inter-particle attraction therefore, no plasticity present in sample. The liquid limit performed by the Static cone penetrometer was 48.62%. The grain size distribution curve has been shown in Figure 1. Pond ash is poorly graded uniform soil with C_u and C_c values of 3 and 1.92 respectively.

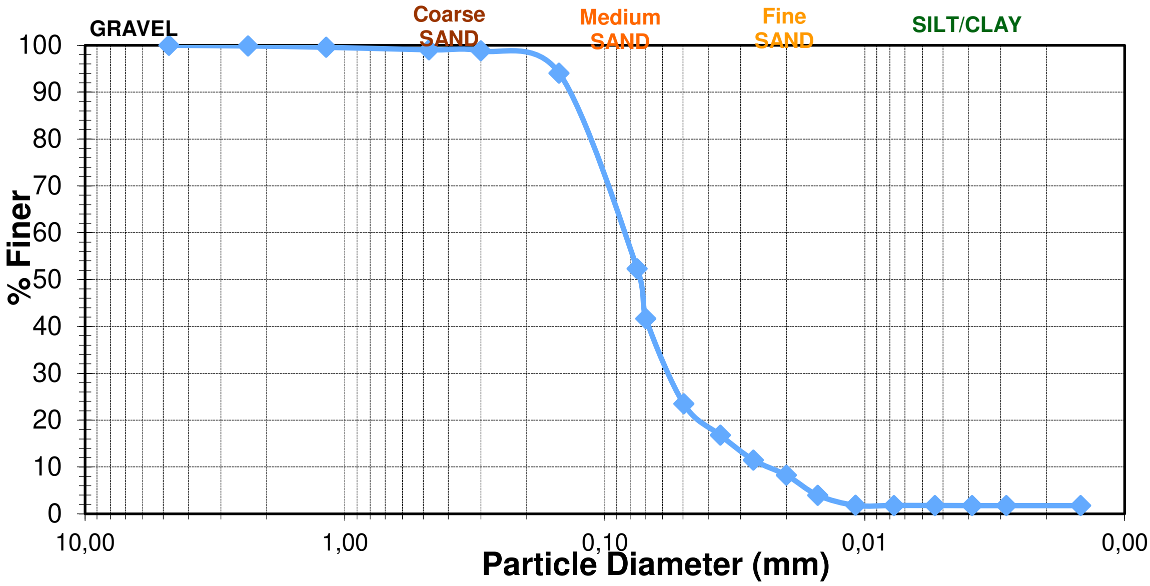

Figure 1: *Grain size distribution curve for pond ash*

4. RESULT AND DISCUSSIONS

In the current study, a comparison was made between the thickness of flexible pavements constructed with pond ash subgrade and those constructed with pond ash subgrade mixed with various amounts of polypropylene fibers. The fiber content used had aspect ratios of 50, 100, and 150, and their effects on pavement thickness were evaluated. Various test results of modified proctor, CBR, UCS and direct shear are discussed.

4.1 Compaction Results

Modified Proctor test is performed for all compositions of pond ash with various fiber percentages at different fiber aspect ratios. Representative test samples of UCS and modified proctor test at different aspect ratios have been shown in Figure 2. As pond ash is a light weight material and has low cohesion, when Polypropylene fiber (PP) is reinforced into the pond ash, the MDD (Maximum Dry Density) increases and OMC decreases. Increase in the percentage of the fiber reinforcement in Pond ash sample causes increase in the maximum dry density and gives maximum 10.7% increment in MDD at $PA1.5PF_{50}$ as shown in Figure 3 (a) because with the addition of fiber in the sample the voids in the sample also decreases thus gives increase in the MDD. Maximum dry density of 12.4 kN/m^3 was observed at 27.4 % water content for 1.5% Polypropylene (PP) fiber mixed in pond ash. At a moisture content of 33%, the Pond Ash sample exhibited the lowest MDD of 11.1 KN/m^3.

Figure 2(a): Representative UCS sample at aspect ratio 150

Figure 2 (b): Representative Modified proctor test sample at Aspect ratio 100.

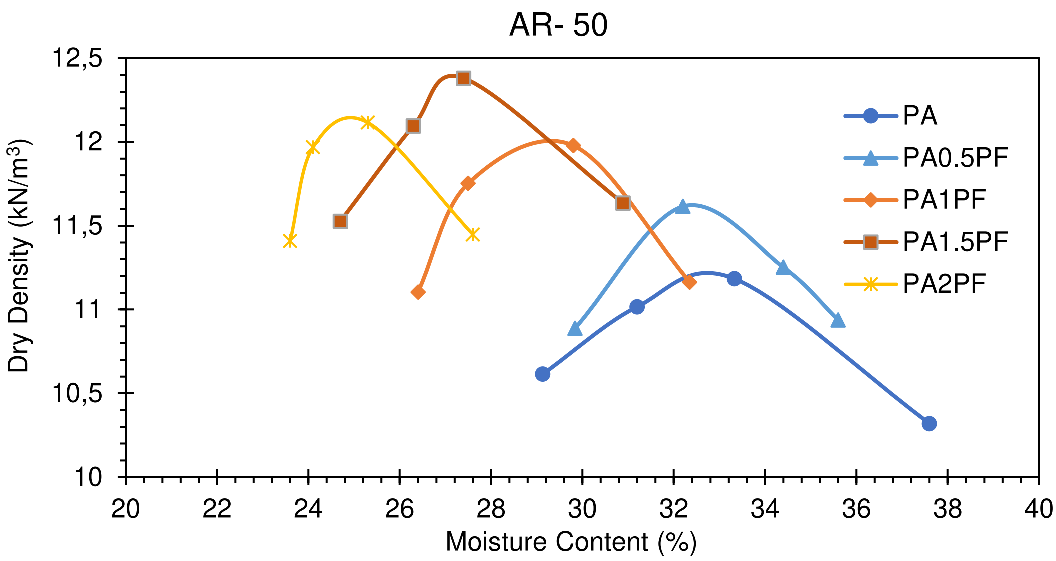

Figure 3(a): *Modified Proctor compaction results for different PP fiber content at AR - 50*

When fiber was added in aspect ratio of 100, a slight variation was observed in the MDD when compare to aspect ratio of 50. Figure 3 shows that when the modified proctor test was conducted with a fibre content of 1.5%, the highest MDD was again found at an aspect ratio of 100, which is slightly better than the results of aspect ratio of 50. Dry density was measured to be a maximum of 13 kN/m^3 for $PA1.5PF_{100}$ at an OMC of 25.7%, an increase of 16.1% compared to a PA sample without fibre, and an increase of 4.1% due to an increase in aspect ratio from 50 to 100 as shown in Figure 3 (b). The optimum moisture content decreases with increase in the fiber content in the mix. OMC decreases by 9.1% for $PA2PF_{100}$ sample as compared to PA. Zero air void line for PA has been shown in Figure 3 (c).

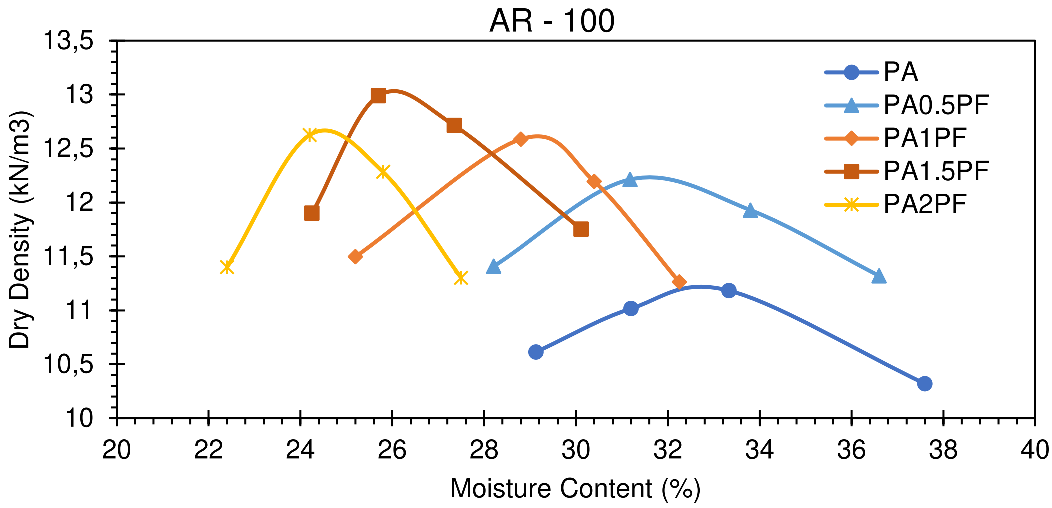

***Figure 3(b)**: Modified Proctor compaction results for different PP fiber content at AR – 100*

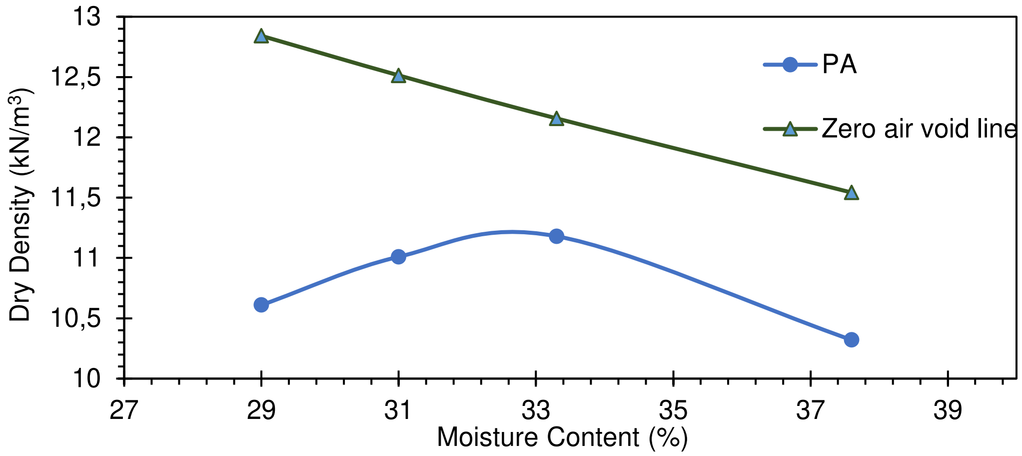

***Figure 3(c)**: Zero air void line and MDD curve for PA sample*

Maximum dry density (MDD) was found to have decreased mildly when the aspect ratio was increased from 100 to 150, perhaps because to the increased likelihood of the problem of inappropriate mix with longer fibres. As the aspect ratio increases, the MDD decreases because longer fibres tend to curl and cluster together during sample mixing and specimen preparation, reducing the compaction of the specimen and hence the MDD.

4.2 California bearing ratio (CBR)

The test results are then plotted in a form of a graph. As such, the CBR value at 5 mm was found out to be more than the CBR value at 2.5 mm. Therefore, the test was repeated and again CBR at 5 mm was higher. The average of value CBR at 5 mm was taken as the CBR value of the pond ash sample. A 4-day soaked CBR analysis to determine the strength of Pond Ash sample at various percentages of polypropylene fibre at various aspect ratios according to IS: 2720 (Part-XVI): 1973 was conducted.

At aspect ratio of 50, an increment of 34% in the CBR values of $PA1.5PF_{50}$, 47% in the CBR values of $PA1.5PF_{100}$, 44% in the CBR values of $PA1.5PF_{150}$ was found over pond ash. From the results it can be concluded that, aspect ratio of 100 is better among the three aspect ratios considered. It could be due to the fact that upon increasing the percent fiber in pond ash sample, the fiber tends to fill the voids initially upto 1.5% and further increase in fiber content decreases the MDD and same is the trend with CBR. This type of behaviour is common among all the three aspect ratios. The CBR values of all the mix composition and for different aspect have been given in Figure 4.

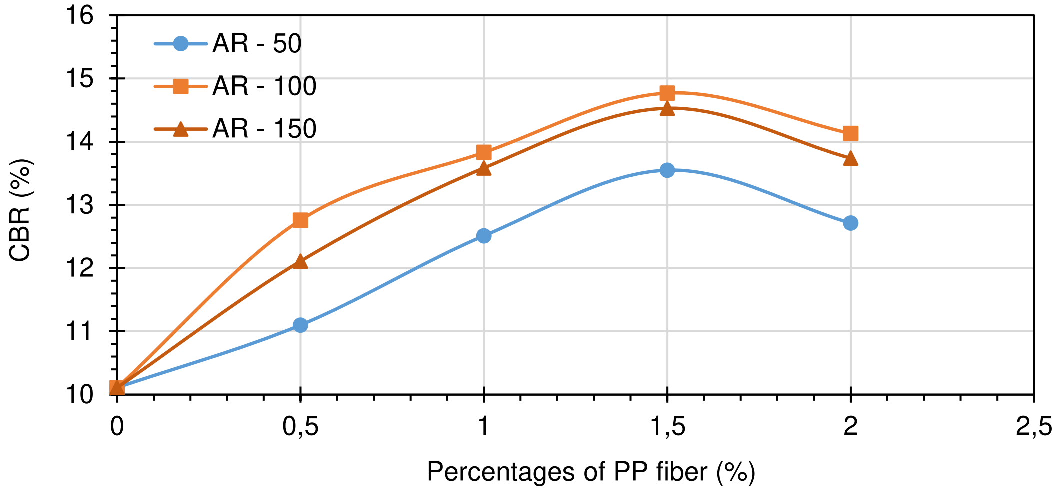

Figure 4: *Plot of CBR v/s percentages of PP fiber for different aspect ratios*

4.3 Thickness of Pavement

A comparison of thickness was done for flexible pavements with conventional soil subgrade and pond ash subgrade mixed with different PF content at aspect ratios of 50, 100 and 150 respectively. A single-lane road stretch of 1 km is selected and the thickness of pavement layer is determined from the CBR values of the subgrade material. The thickness of a pavement layer for constructing a road and the cost analysis of the construction per kilometre per lane can be influenced by the CBR (California Bearing Ratio) value. Generally, a higher CBR value indicates that less thickness of pavement is required for construction. This is because a higher CBR value implies that the subgrade has a higher load-bearing capacity, and therefore can support the weight of the vehicles and pavement more effectively, resulting in a lower required thickness of pavement. The strength of subgrade for design shall not be less than 5% (at least fair), even when the traffic volumes are low as per code IRC – 37 (2018). In case the CBR of the subgrade soil is less than 5%, the subgrade should be stabilized to achieve a minimum design CBR of 5%, i.e. the quality of sub-grade for design purposes should be at least fair. The subgrade strength is divided into the following classes as mentioned in Table 2.

Table 2: *Classification of Subgrade strength and CBR range (IRC: SP:77-2008).*

QUALITY	SUBGRADE CLASS	CBR RANGE (%)
Very Poor	S_1	1-2
Poor	S_2	3-4
Fair	S_3	5-6
Good	S_4	7-9
Very Good	S_5	10-15

The CBR value of pond ash is in very good quality S_5 range with CBR value of 10.1 percent, while the maximum CBR value of Pond ash that could be achieved was upon addition of 1.5 percent polypropylene fiber (CBR = 14.8 percent at aspect ratio 100) i.e. almost about 50% improvement in CBR value of pond ash. Higher the CBR value, lesser is the total thickness of pavement which is helpful in keeping the expenditure under control. The cost analysis was carried out for low volume roads and compared for two traffic conditions as per IRC:SP-72-2015, 20 Million standard axles (MSA) and 50 MSA respectively. It is possible to reduce the total thickness by 30 mm for 20 MSA and 20 mm for 50 MSA when pond ash is mixed with 1.5% polypropylene fiber at an AR of 100 as shown in Figure 5 and 6. Change in PF percentages resulted in no change in Water mix macadam (WMM) and Granular sub base (GSB).

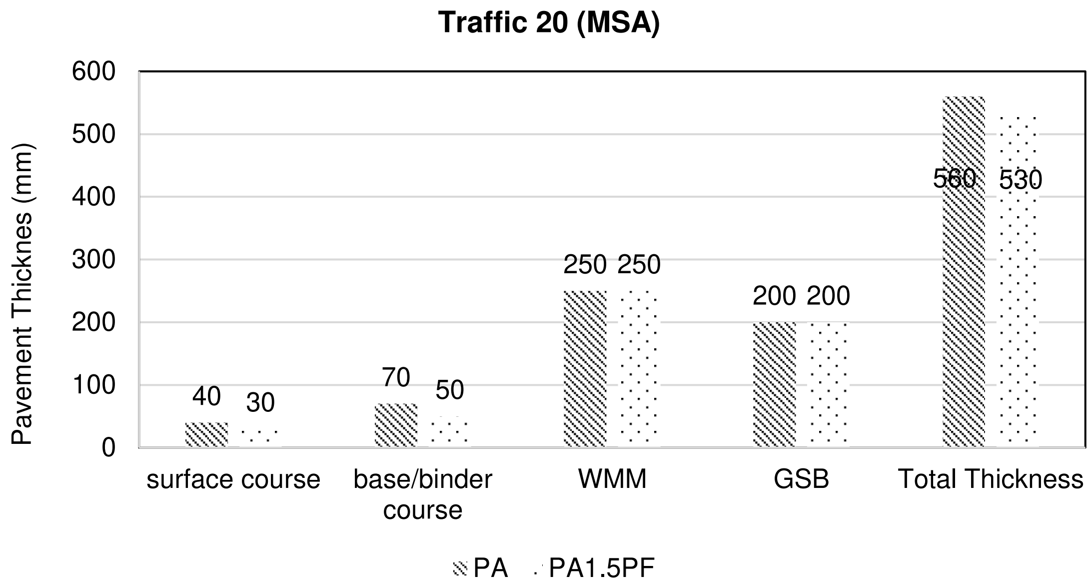

Figure 5: Thickness Comparison of PA and PA1.5PF100 at traffic of 20 MSA

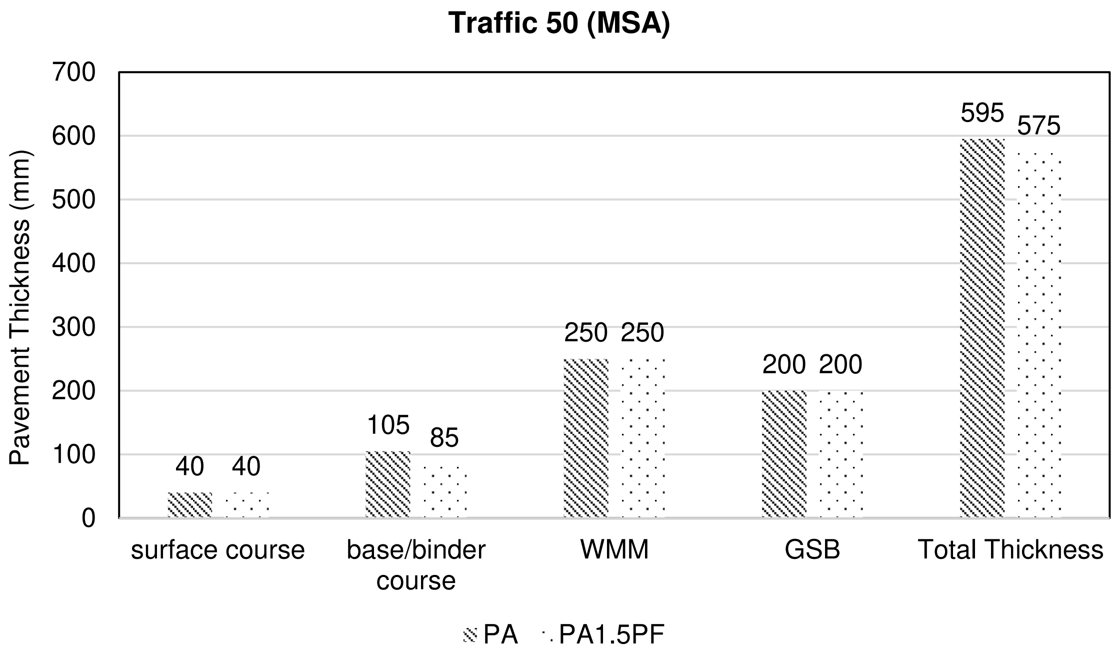

Figure 6: Thickness Comparison of PA and PA1.5PF100 at traffic of 50 MSA

4.4 Unconfined Compressive Strength (UCS)

When UCS test was conducted on pond ash sample, the nature of failure was found brittle with a value of 38.7 kPa and a strain value of 3.3 percent. Brittle failure occurs owing to a less cohesion in the pond ash sample, which made the specimen less resistant to uniaxial pressure in longitudinal direction. For all three aspect ratios UCS value peaked upon addition of PF of 1.5% to PA as shown in Table 3. Up until the addition of 1.5% polypropylene fibre, the UCS value rose when polypropylene fibre was added; after that point, further additions caused the UCS value to decline. Additionally, it was observed that the UCS value of PA-PF is greater for an AR of 100 compared to an AR of either 50 or 150. According to the outcomes of this research, out of all the mixed compositions that were taken into consideration, PA1.5PF100 is the better sample.

Table 3: Variation of UCS (kPa) for all the mixes at an aspect ratio of 50, 100 and 150

Aspect Ratio	**50**		**100**		**150**	
PA + PF	**Strain (ε)**	**UCS (kPa)**	**Strain (ε)**	**UCS (kPa)**	**Strain (ε)**	**UCS (kPa)**
PA	0.033	38.7	0.033	38.7	0.033	38.7
PA0.5PF	0.023	44.1	0.033	73.2	0.023	65.7
PA1PF	0.033	57.9	0.040	106.5	0.036	88.2
PA1.5PF	0.036	111.3	0.059	170.7	0.049	147.6
PA2PF	0.036	81.9	0.043	147.9	0.043	122.4

4.5 Effect of Slope on FoS

Limit Equilibrium Analysis was carried out for two different slopes (1V:2H, 1V:1.5H) ranging from 10 -30 m height made from PA and PA-PF. The $PA1.5PF_{100}$ was chosen on the basis of the results of CBR, UCS and Direct shear testing. The slope stability analysis has been carried out on GEOSTUDIO (2021) for slopes without berm for the purpose of comparision. The piezometric line was made at half of the height of embankment constructed above 10 m impermeable bed rock which remained same for all cases. Factor of safety (FOS) of Pond ash (PA) and $PA1.5PF_{100}$ is compared. It has been observed that the embankment made entirely of pond ash is not safe even at the height of 10 m as for safe design the FOS should be equal to or greater than 1.5. Pond ash slope is critical for almost all the heights as FOS is less than 1.5. When PF was added in the PA, the FOS increased as shown in Table 4. The FOS of $PA1.5PF_{100}$ composition that comes out to be more than 1.5 at every height analyzed at slope 1V: 2H shown in Table 4. A representative screenshot of PA embankment with height of 4 m and 10 m with slip circle is shown in Figure 7 and 8. Designing a highway embankment using only pond ash results in a factor of safety that exceeds 1.5. However, this high level of safety comes with a limitation on the maximum height that can be achieved, which is 4 meters. In other words, using pond ash as the sole material for an embankment can ensure stability and prevent failure, but it is important to consider the height limitations. For a steep slope of 1V: 1.5H, the FOS come out to be less than 1.5 for 20 and 30 m heights as shown in Table 4. For 10 m height of embankment, it was safe and FOS showed improvement in rest of the cases analyzed when PF (1.5%) was added. It was observed that FOS decreases when the height of embankment was increased.

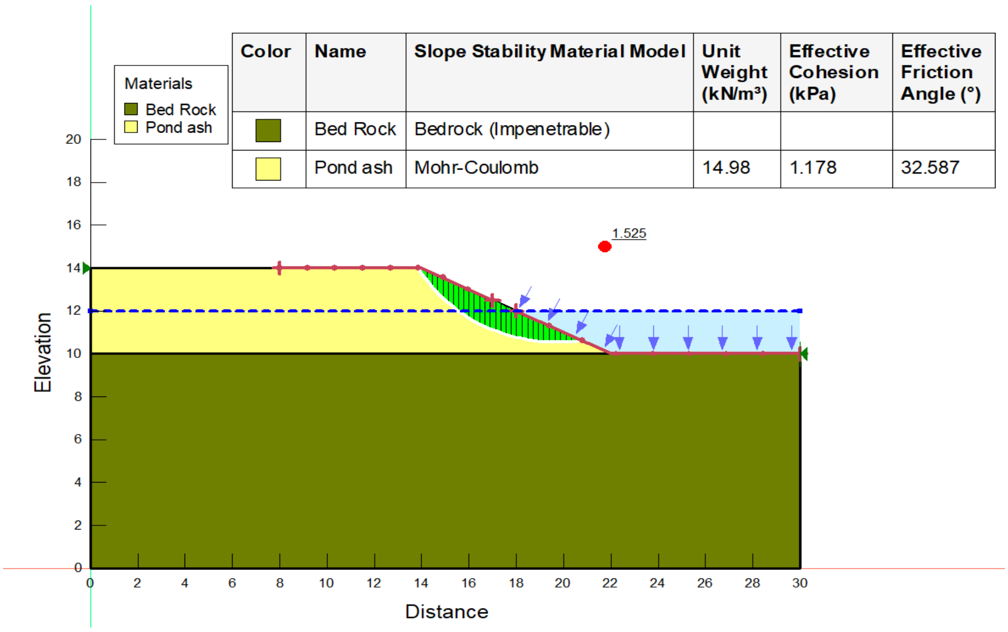

Figure 7: Design of Pond Ash Embankment of 4 m height at slope 1V:2H

Table 4: Comparison of Factor of safety between Pond ash and PA1.5PF$_{100}$ at slope 1V:2H and 1V:1.5H

Composition	**Height (m)**	**Unit Weight (kN/m^3)**	**Effective Cohesion (kPa)**	**Effective Friction Angle (^{0})**	**Slope**	**FOS**	**Slope**	**FOS**
Pond ash	4	14.98	1.17	32.58	1V:2H	1.52	-	-
Pond ash	10	14.98	1.17	32.58	1V:2H	**1.33**	1V:1.5H	**1.33**
PA1.5PF$_{100}$	10	16.31	2.59	41.12	1V:2H	1.94	1V:1.5H	1.56
Pond ash	20	14.98	1.17	32.58	1V:2H	**1.26**	1V:1.5H	**0.99**
PA1.5PF$_{100}$	20	16.31	2.59	41.12	1V:2H	1.81	1V:1.5H	**1.44**
Pond ash	30	14.98	1.17	32.58	1V:2H	**1.23**	1V:1.5H	**0.96**
PA1.5PF$_{100}$	30	16.31	2.59	41.12	1V:2H	1.75	1V:1.5H	**1.39**

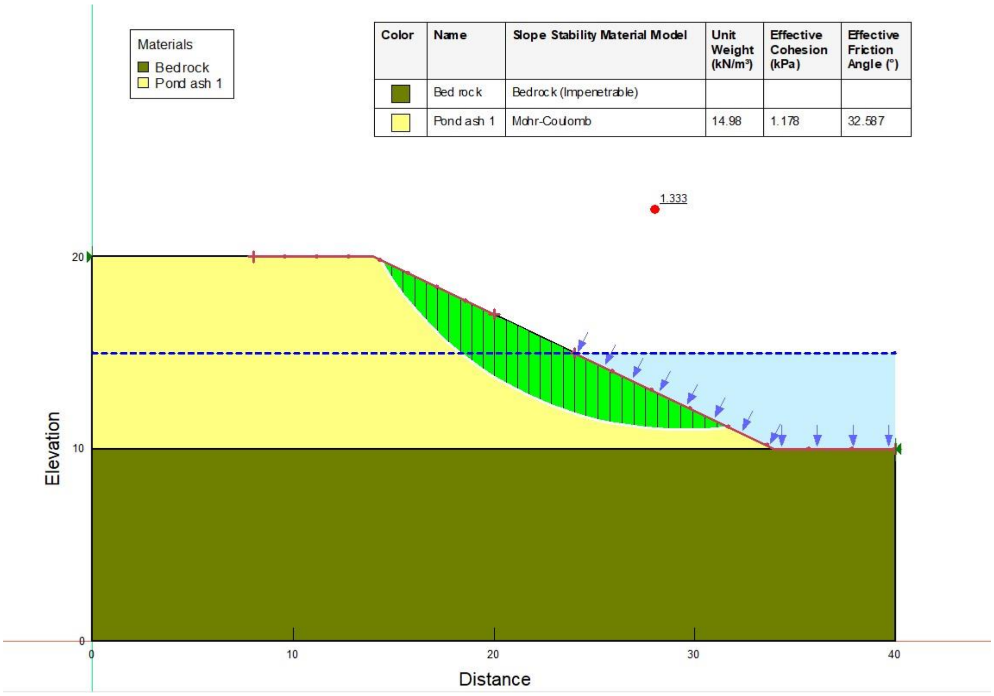

Figure 8: Design of Pond ash embankment of 10 m height at slope 1V:2H

Design of highway embankment made of PA1.5PF$_{100}$ composition material fails in case when slope is provided is 1V:1.5H as FOS of this composition material embankment comes out to be less than 1.5 at 20 m and 30 m height so to increase the factor of safety so as to make a stable highway embankment the berms of 3 m were provided and FoS was reworked for 20 and 30 m height. FoS was increased from 1.44 to 1.83 and 1.39 to 1.57 with addition of 3m berm which provided stability to the embankment slope.

5. CONCLUSIONS

The present study was conducted to analyse the effect of percentage variation of polypropylene fiber in pond ash sample at different aspect ratios keeping in view to be used in highway embankments. Experiments were performed to find out the geotechnical properties of pond ash sample and to analyse the effect of the polypropylene fiber on pond ash so that the composition can be used in the design of highway embankment. Slope analysis has been done on geo-studio software by designing embankments at different heights and Comparison of factor of safety has been made between pond ash and Pond ash with fiber reinforcement. On the basis of experiments performed and analysis done on Geo-studio software following conclusions have been drawn:

- Maximum dry density showed maximum increase of 16 % on addition of 1.5% fiber content at aspect ratio 100. Optimum moisture content decreases on addition of Polypropylene fiber to pond ash by 9.13 %. This decrease may be attributed to the properties of Polypropylene fibre as the fiber doesn't need water for its compaction nor it absorb water.
- The increase of about three times in the value of UCS is observed on addition of 1.5% fiber content at aspect ratio of 100 in the pond ash sample.
- CBR value for a particular aspect ratio increases with increase in polypropylene fiber up to 1.5%. An increase of about 50% is observed in CBR value when fiber content of 1.5% added to PA at an aspect ratio of 100. Thus, it can be safely said after observing the CBR values for all aspect ratios, the optimum value of soaked CBR is attained at a fiber content of 1.5% at aspect ratio of 100.
- From a point of view of construction of pavement, it is advisable to use pond ash with polypropylene fiber, as the CBR value for pond ash with fiber comes out to be more in comparison to the Pond ash sample and hence the total thickness of pavement construction using this composition comes out to be less in comparison to be Pond ash sample.
- Using only pond ash to build a highway embankment is safe because it has a factor of safety of over 1.5. However, the height of the embankment needs to be limited to 4 meters. However, adding 1.5% PF to the pond ash can increase the FOS to over 1.5 for heights up to 30 meters with a slope of 1V to 2H without berms. But, when designing an embankment with a slope of 1V to 1.5H using the same material with fiber content, the FOS is less than 1.5 for heights of 20 and 30 meters.

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