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PERFORMANCE ANALYSIS OF FLEXIBLE PAVEMENT WITH REINFORCED ASH

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Abstract Coal ash produced from thermal power plants as a substitute for conventional construction material has increased considerably in recent years. In the past, studies on partial replacement of soil were carried out with a single type of ash. Because of the insufficient evidence, limited research has been initiated on the productive usage of Fly and Bottom Ashes. This paper aims to study the properties of these materials and investigate their efficacy in road construction. Laboratory investigations were conducted to assess chemical and physical properties and mechanical performance to evaluate both ash types in pavement construction. The rutting factor is calculated for various combinations of coal ash materials with the addition of polypropylene fiber as a reinforcement in increments of 0.1% of its total weight with an aspect ratio of 200. The analytical tool ANSYS is used to validate the service life, vertical strain and quality of reinforced ash materials.

Keywords: Reinforced Ash, Polypropylene Fibres, ANSYS, Vertical Strain, Service Life Ratio, Rutting Factor.

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1. INTRODUCTION

In developing countries like India, the naturally available materials of aggregates and soil are used for road construction and hence result in a severe scarcity of these conventional materials [2]. Fig. 1 implies the production of fly ash and bottom ash with their respective percentages of usage (rather than disposal) in the United States. It reveals that, on average, more than 45% of ash is meant to be disposed of without any proper utilization [9]. Coal-based thermal power plants are the major source of power generation in India, thermal power plants produce more than 130 million tons of fly ash per year as a waste product, out of which merely 35% is utilized. Fly ash which can be used in a huge manner is available free of charge at thermal power plants [8]. The flowability of a soil fly ash mixture was considerably improved with the addition of fly ash in flowable fill [21].

Fig. 1. Production and Use of Ash with Percent

a - Bottom Ash Production and Usage; b - Fly Ash Production and Usage

The strength of a road depends on subgrade soil strength; if the strength of the soil is insufficient, it should be strengthened via soil stabilization techniques with a suitable combination of ash mixtures [11, 19].The coefficient of permeability (k) of ash combinations, started to decrease slightly with each additional increment of fly ash [15]. Ash used to reduce the pavement thickness and cost of the construction [5]. Fly ash embankment has been used in over ten countries since it has several advantages like low unit weight and high shear strength [3]. The ANSYS computer code will predict the stress-strain characteristics and distribution on each layer of a pavement and it acts as a damage prediction parameter [1]. This paper focuses mainly on the study of the geotechnical properties of reinforced ash as the mixture of fly ash and bottom ash with polypropylene fibres and its performance is evaluated using ANSYS.

2. MATERIALS USED

2.1 FLY ASH AND BOTTOM ASH

Class F fly ash and bottom ash, grey colour and black colour respectively as a byproduct obtained from the Neyveli Lignite Corporation.

2.2 POLYPROPYLENE FIBRE

Fibre with an aspect ratio of 200 collected from Tashi Reinforcements, Nagpur, is used in this study. This fibre is used as a reinforcement to improve the CBR value and enhance the stress-strain properties of an ash material. The content proportions of the fibres and their aspect ratio decides the strength parameters of the materials used [18].

3. TESTS AND RESULTS

3.1 GRAIN SIZE ANALYSIS

The gradation process involved as per IS2720-Part4, for fly ash, bottom ash, and combined mixtures of fly and bottom ash. Indian Standard (IS: 2720) is the code book referred in India regarding the testing method of various types of soil; this code reveals the basic properties of a material and its suitability for the environment. The gradation implies that the fly ash sizes occurred within the range of 0.001 mm to 0.075 mm and the mixture of bottom ash increases the curvature to nearly 0.075mm, and hence proves to be a better graded mixture.

3.2 CHEMICAL COMPOSITION

The presence of silicon di-oxide in fly ash is known to be higher than the bottom ash and hence class F fly ash possesses more pozzolanic properties, whereas loss on ignition (LOI) for bottom ash is comparatively much higher, and while on combination of both type of ash we obtain less than 10% LOI. The issue of leaching is minimum.

3.3 SPECIFIC GRAVITY

Specific gravity of coal ash is decided by the chemical composition and amount of hollow particles present within ash materials [6]. The values obtained for the specific gravity of fly/ bottom ash and mixtures ranged from 2.35 to 2.7. A higher amount hollow particles results in lower specific gravity thus hollow particles and specific gravity are inversely proportional.

3.4 COMPACTION CHARACTERISTICS

A modified Proctor compaction test is done as per IS2720-Part 8 and the relationship between optimum moisture content (OMC) and maximum dry density (MDD) is obtained. The ash is meant to be reinforced by polypropylene fibres (PPF) increments of 0.1% of total sample weight. At the point of addition 0.5% of weight, the results show a balling effect. Hence it is limited to 0.5% and Fig 2 illustrates the compaction curve obtained for reinforced ash at an addition of 0.5% weight of the total sample weight of the polypropylene fibre.

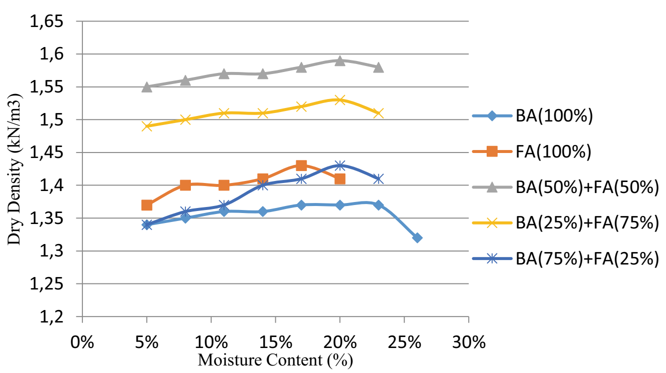

Fig 2. Modified Compaction Curve for 0.5% PPF in Ash Mixtures

3.5 pH AND CONDUCTIVITY

The pH of the sample is noted in the range of 8.49-9.82, showing that it possess alkaline characteristics. A falling head permeability test is performed a using standard compaction mould, a substantial head loss occurs through the thick porous stone in the base. A specimen with an increased amount of dry density probably has more of a reduction in hydraulic conductivity [11, 20]. The conductivity of reinforced bottom ash is reduced when the reinforced fly ash content increases.

3.6 DIRECT SHEAR AND CALIFORNIA BEARING RATIO

The direct shear test is conducted to determine the angle of shearing resistance of bottom ash, fly ash, combined samples as per IS 2720-part 39. Three specimens are tested under each application of a normal load. The angle of internal friction is obtained in the range of 27.9^{0} – 32.37^{0}, whereas that of the local soil will be 28^{0}. As per Indian Standard IS 2720- Part 16, the California bearing ratio (CBR) test was carried for bottom ash, fly ash, and bottom ash+ fly ash+ polypropylene fibre mixture. As mentioned above, the polypropylene fibre is added in an increments of 0.1% and limited to 0.5% total addition, and hence the CBR obtained for various mixtures of bottom and fly ash are shown in Fig 3.

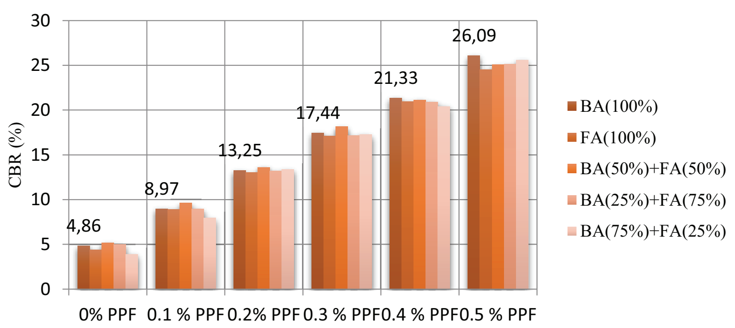

Fig 3. CBR for Ash Mixtures with increment of 0.1% PPF

4. FINITE ELEMENT ANALYSIS AND VALIDATION

4.1 DETERMINATION OF MODULUS OF ELASTICITY

The modulus of elasticity (E) for each layer is required to obtain the stress-strain characteristics in ANSYS. The CBR test is the traditional method to calculate the modulus of elasticity by developing equation (4.1) for the modulus of subbase reaction [10].

$$K_s = 1.13 \frac{E}{(1-\vartheta^2)} \frac{1}{\sqrt{A}} \qquad (4.1)$$

The base material used in the present study was of water bound macadam (WBM) type as this material is the most commonly used for base courses in India. Dense bituminous macadam (DBM) is the next layer of pavement, laid immediately above the base course, whereas bituminous concrete (BC) is the wearing course provided above the DBM for a smooth riding surface. Specimens of size 100 mm in diameter and 200 mm in height were prepared as per ASTM D 3496 (1999) and obtain deviatoric stress and axial strain were obtained for WBM, DBM and BC. The values of the initial tangent modulus, E (MPa) were obtained for WBM, DBM, and BC; they are 164.6, 720 and 1040 respectively. The E values obtained for various reinforced ash mixtures are shown in Table 1.A Poisson’s ratio of 0.4 for subgrade soil and 0.35 for all other layers was assumed [6].

Table 1.Modulus of Elasticity and Poisson’s Ratio for Reinforced Ash Mixtures

Materials	**Bottom Ash**	**Fly ash**	**BA (50%) + FA (50%)**	**BA (25%) + FA (75%)**	**BA (75%) + FA (25%)**
Young’s modulus MPa	91.17	85.65	87.57	87.78	89.45

4.2 MODEL DIMENSIONS AND MESHING OF PAVEMENT

A typical ANSYS analysis has three distinct steps: building a model, applying loads, and reviewing the results [20]. As per the Indian Code of Practice (IRC: 37-2001), the thickness of each layer above the subgrade is designed for an assumed design traffic intensity of 100 million standard axles (msa). Fig 4 shows the various layers ‘pavement thickness (cm).

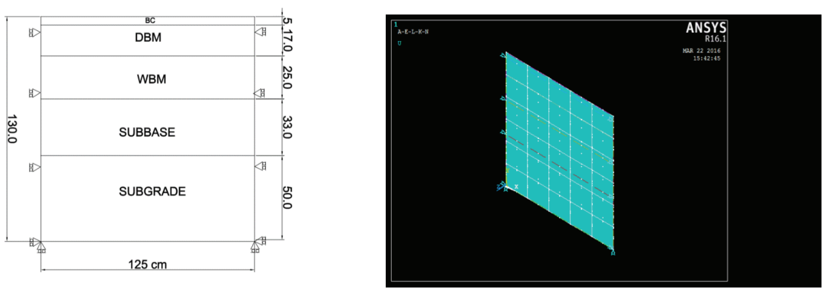

Fig 4.Pavement Section. a - Finite Element of Pavement Section; b - Boundary Condition of FE Model

Five-layered pavement was assumed to behave linearly and elastically under the applied static pressure of 575kPa, caused by considering at single axle wheel load of 4080kg on a circular contact area with a radius of 150mm. Rotational constraints were used to restrain the subgrade support in the pavement structure.

4.3 EVALUATION OF STRAIN CHARACTERISTICS

ANSYS was effectively used to measure the vertical strain at the top of the subgrade layer. The multilinear isotropic elastoplastic hardening model was employed to measure the vertical strain at the top of the subgrade layer by applying uniform pressure of 575kPa. Fig 5 resembles the strain at the top of the subgrade layer.

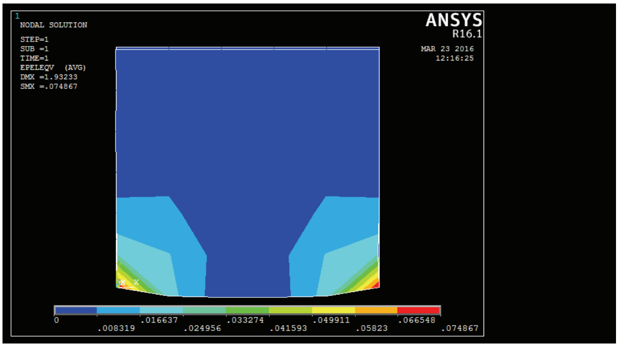

Fig 5. Vertical Strain at Top of Subgrade

4.4 LABORATORY VALIDATION OF ANSYS

The plate load test was conducted in a laboratory on a small scale of application of the load for the purpose of validating the ANSYS program with a field study. The main aim of this study is to conclude whether the strain characteristics obtained in the laboratory are behaving similarly to the finite element discretization through ANSYS.

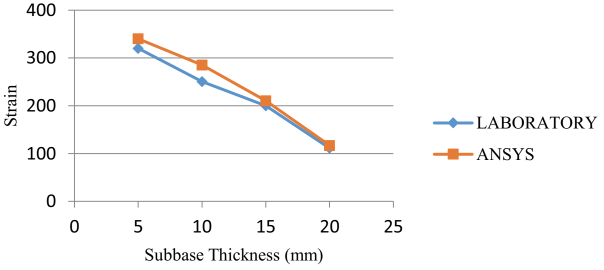

Fig 6. Laboratory and ANSYS Comparative Stipulation for Validation

A laboratory plate load test was conducted in a pit 450mm x 250mm in size and a 50 mm thick layer of combined FA & BA was compacted at its maximum dry density and optimum moisture content. A uniform pressure of 343N was applied and its suitable deflections at various depths are obtained by a deflectometer. Fig 6 shows laboratory and ANSYS comparative stipulation for validation.

4.5. EFFECT OF SUBBASE MATERIALS ON PAVEMENT RESPONSE

The performance of reinforced ash material in the subbase layer was analyzed through sensitivity analysis by changing the thickness of the subbase [17]. The quality is analyzed by the E values obtained. The vertical strain at top of the subgrade layer at its maximum in the case of fly ash, followed by BA (50%) + FA (50%), BA (25%) + FA (75%), BA (75%) + FA (25%), bottom ash.

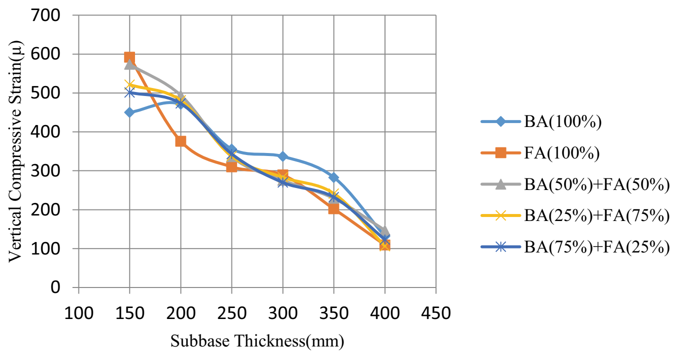

Fig 7.Vertical Compressive Strain at Top of Subgrade vs. Subbase Thickness

From Fig.7, it is visible that the thickness of the subbase and the amount of strain developed are indirectly proportional. The lower the strain - which implies low effects on rutting - the higher the life span of the pavement.

4.6 ESTIMATION OF PAVEMENT LIFE

Due to an application of a load by a wheel above road results in the formation of vertical compressive strain at the top of the subgrade. Hence, this stress results in the formation of surface cracking and rutting. Since the scope of the present study is limited to replacing the bottom ash and fly ash obtained from industry wastes rather than from other local materials, rutting has been marked as a failure criterion. As per IRC: 37-2001, equation 4.2 was suggested by considering a rut depth of 20 mm as the failure criterion for flexible pavement.

$$N_R = 4.1656*10^{-8} \, [1/€_Z]^{4.5337} \quad (4.2)$$

Where N_R – the number of cumulative standard axles to produce rutting of 20mm, $€_Z$ – vertical subgrade strain. Laboratory test results imply that out of five combinations, the fly ash (100%) and BA (50%) +FA (50%) mix is the strongest combination material hence its service life is more than 70%.

5. CONCLUSIONS

1. The California bearing ratio obtained was raised from 5 to 25 percent via the process of fibre reinforcement. The value of 25 percenta with tolerance limit of ±5 percent can be used as a subbase material as per Morth Specifications 2001.
2. Improving fly ash addition percentage with bottom ash results in the reduction of permeability. Bottom ash and fly ash of a 50/50 percent combination can be used in the subbase for flexible pavement since it moderately performs hydraulic conductivity.
3. Fly and bottom ash can be used in embankment and subgrade mixes, hence the value of CBR is more than 5%.
4. Bottom ash has a high LOI compared to fly ash, and in a combination of 75 percent fly ash and 25 percent bottom ash where it has the normal loss on ignition (LOI) of 6.25%.
5. The pH implies that the ash and ash mixtures are meant to behave as acidic.
6. The vertical compressive strain attained consistently decreases with an increases in subbase total thickness and hence prolongs the lifespan of the pavement; the thickness of the subbase can be increased with the low cost of reinforced ash mixtures.
7. Rutting as a failure criterion implies that fly ash and a 50percenat combination of reinforced fly ash and bottom ash is known to have a comparatively higher service life (more than 70%).
8. The laboratory plate load test implies that results obtained are about 92.6 percent similar. Apart from the present study more research needs to be done on various combinations of other industrial waste materials in order to reduce the scarcity of conventional materials.

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Table 1. Modulus of Elasticity and Poisson's Ratio for Reinforced Ash Mixtures

Tabela 1. Współczynnik sprężystości i współczynnik Poissona dla mieszanin popiołu ze wzmocnieniem

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ANALIZA OSIĄGÓW ELASTYCZNEJ NAWIERZCHNI Z DODADTKIEM POPIOŁU

Słowa kluczowe: dodatek popiołu, włókna polipropylenowe, ANSYS, odkształcenie pionowe, współczynnik żywotności, czynnik kolein

Streszczenie:

Niniejsze opracowanie zostało poświęcone zastosowaniu podczas budowy dróg materiałów wzmocnionych popiołem jako zamienników pierwotnych surowców. Badania były prowadzone przez ostatnie cztery lata w skuteczny sposób w celu uzyskania pozytywnego wyniku. Wskazówki kolegów oraz doświadczonych profesorów pomagają wypracować właściwe podejście do badań. Ponadto, studenci z PSNACET również odegrali istotną rolę w przeprowadzaniu badań laboratoryjnych. Materiały zastosowane w badaniu obejmowały: popiół denny, popiół lotny oraz włókna polipropylenowe (PPF). Popiół denny jest produktem ubocznym pozyskiwanym w przemyśle energetycznym w wyniku spalania węgla w piecu. Ma kolor czarny oraz szorstką konsystencję ze śladowymi ilościami klinkieru żwiru. Popiół lotny składa się z drobnych cząstek, które są wyjmowane z kotła wraz z gazami spalinowymi. Materiały te są bezpłatnie pozyskiwane od „Neyveli Lignite Corporation". Włókno polipropylenowe jest polimerem termoplastycznym o wysokiej odporności na działanie substancji chemicznych, kwasów i zasad. Wykorzystywane do badań włókno o współczynniku kształtu wynoszącym 200 pozyskiwane jest z Tashi Reinforcements, Nagpur.

Przeprowadzono wiele badań laboratoryjnych w odniesieniu do tych materiałów, zarówno w kombinacji indywidualnej jak i mieszanej, obejmujących: popiół denny (100%), popiół lotny (100%), popiół denny (50%) + popiół lotny (50%), popiół denny (25%) + popiół lotny (75%) oraz popiół denny (75%) + popiół lotny (25%) z dodatkiem 0,1% włókna polipropylenowego jako wzmocnienia oraz ograniczenia dodatku do 0,5% ze względu na efekt formowania w kulę. Liczne badania obejmują analizę właściwości wilgotności, składu chemicznego, rozkładu wielkości ziaren, ciężaru właściwego, zmodyfikowanego zagęszczenia Proctora, kalifornijskiego wskaźnika nośności (CBR), bezpośredniego ścinania, pH i przewodności. Wyniki badań laboratoryjnych zostały podane w odniesieniu do naturalnej gleby. Uzyskany kalifornijski wskaźnik nośności wzrósł z 5 procent do 25 procent w procesie wzmacniania włókien. Wartość 25 procent z limitem tolerancji wynoszącym +5 procent może być zastosowana jako materiał podłoża zgodnie ze Specyfikacjami Morth z 2001 roku. Poprawa procentowej zawartości popiołu lotnego z dodatkiem popiołu dennego powoduje zmniejszenie przepuszczalności. Popiół denny i popiół lotny w 50-cio procentowej kombinacji można zastosować w podłożu dla gładkiej nawierzchni, ponieważ ma umiarkowany wpływ na przewodnictwo hydrauliczne. Popioły denne i lotne mogą służyć jako nasyp i podłoże, a zatem wartość CBR przewyższa 5%. Popiół denny charakteryzuje się wysokim LOI w porównaniu do popiołu lotnego oraz w kombinacji 75 procent popiołu lotnego i 25 procent popiołu dennego, w przypadku której następuje normalna strata przy zapłonie (LOI) wynosząca 6,25%. Współczynnik pH sugeruje, że popiół i jego mieszaniny mają charakteryzować się kwasowością.

W odniesieniu do CBR otrzymano moduł sprężystości dla różnych kombinacji materiałów. Model ANSYS został opracowany w odniesieniu do wyników pozyskanych z laboratorium. Zgodnie z indyjskim kodeksem postępowania (IRC: 37-2001) grubość każdej warstwy powyżej podłoża została opracowana z myślą o przyjętym natężeniu ruchu wynoszącym 100 milionów standardowych osi (msa). Przyjęto, że pięciopłaszczyznowa nawierzchnia zachowuje się

w sposób liniowy i elastyczny w stosunku do zastosowanego ciśnienia statycznego wynoszącego 575 kPa, co było wynikiem przyjęcia obciążenia kół pojedynczych osi wynoszącego 4080 kg dla okrągłego obszaru styku o promieniu 150 mm. Wykorzystano obciążenia rotacyjne w celu powstrzymania podparcia podłoża w strukturze nawierzchni. Badanie obciążenia płyty zostało przeprowadzone w laboratorium przy małej skali obciążenia w celu zatwierdzenia programu ANSYS wraz z badaniem terenowym. Głównym celem tego badania było sprawdzenie czy właściwości szczepu uzyskane w laboratorium są podobne do dyskretyzacji elementów skończonych w ramach ANSYS. Badanie laboratoryjne dotyczące obciążenia płyty sugeruje, że uzyskane wyniki są podobne w 92,6 procentach. Wartość pionowego obciążenia ściskającego konsekwentnie się obniżała wraz ze wzrostem całkowitej grubości podłoża, a zatem w celu wydłużenia żywotności nawierzchni istnieje możliwość zwiększenia grubości podłoża przy niskich kosztach wzmocnionych mieszanin popiołu. Koleinowanie jako kryterium niepowodzenia oznacza, że popiół lotny oraz 50-cio procentowa kombinacja wzmocnionego popiołu lotnego i popiołu dennego mają stosunkowo wyższy okres żywotności, przekraczający 70%. Oprócz obecnego badania konieczne jest przeprowadzenie większej ilości badań nad różnymi kombinacjami innych odpadów przemysłowych oraz zmniejszenie niedoboru materiałów konwencjonalnych.