Resilient modulus of compacted fly ash for pavement applications

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Abstract. Fly ash is one of the waste materials generated in large quantities across India. As per central electricity authority (CEA) report, nearly 196 million tons of fly ash is generated in the year 2017-18 in India from nearly 167 thermal power stations. Of the generated quantity, only about 60% is utilized for various applications, and a minor portion of it (about 3.4%) is being utilized in roads and flyovers. This study focusses on utilization of fly ash in large-volume embankment construction. When pavements are built over compacted fly ash, resilient modulus (M_R) of compacted ash is one of the key factors considered in the design of pavements. In the present study, fly ash collected from Neyveli Lignite Corporation (NLC), Neyveli, India is used to evaluate the resilient modulus of compacted fly ashes. Cyclic triaxial setup is used to test the resilient modulus of the fly ash. The resilient modulus tests are conducted at three different water contents, optimum water content and ± 2% of optimum water content. Samples are cured for two different curing periods, equal to 6 hours and 24 hours. The resilient modulus tests showed that the fly ash exhibited good pozzolanic property with the passage of time. The M_R value at OMC for fly ash at 6 hours of curing is in the range of 70-80MPa, whereas for 24 hours of curing the M_R value is in the range of 80-115 MPa. The proposed M_R can be helpful to designers to design the thicknesses of pavement layers constructed over embankments made up of compacted fly ash.

Keywords: Resilient modulus, Pavement, Fly ash, Waste materials.

1 Introduction

Resilient modulus (M_R) is considered as one of the important design parameters for any pavement material. Resilient modulus of any soil is evaluated under the application of isotropic confining pressure and repeated loading. Cyclic triaxial test is used to recreate the stress conditions that in general occur in the base and subgrade pavement layers. For the pavement design, U.S. Federal Highway Administration considers resilient modulus as the primary performance parameter.

Resilient modulus defines the response of pavement material to the repeated loads. Resilient modulus is the measurement of the elastic property of soil recognizing certain nonlinear characteristics. M_R is defined as the elastic modulus based on the recoverable strain under repeated loading (see Fig. 1).

$$M_R = \frac{\sigma_d}{\varepsilon_r} \quad (1)$$

where, σ_d is the deviator stress, and ε_r is the recoverable strain under repeated loading.

Many studies are available on determining resilient modulus of the soils used for base, subbase, and subgrade layers in a pavement. Petry et al. (2008) determined resilient moduli of 27 common Missouri subgrade soils and also of five unbound granular base materials. They noticed a loss in M_R for the soils with the increase in the percentage of fines in the soil. Sheng (2010) developed correlation between the subgrade soil resilient modulus and the modulus of subgrade reaction, and also the correlation between the laboratory resilient modulus and the resilient modulus measured using test-pit in the field.

Fig. 1 shows the developments of elastic and plastic strains for the repeated loading on the soil samples.

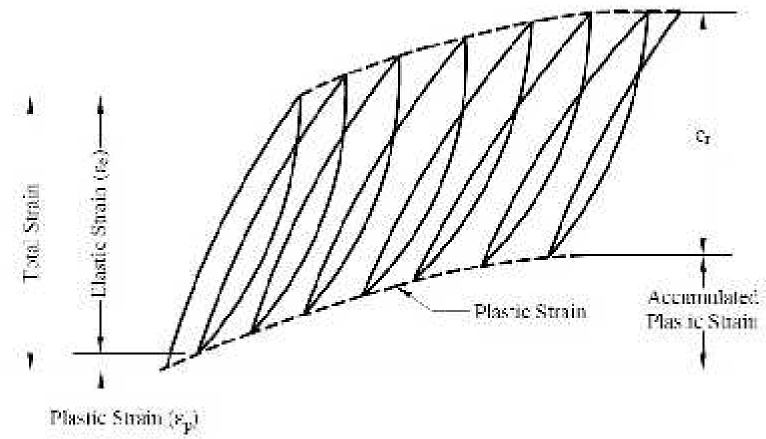


Fig. 1. Applied load versus accumulated strain (modified after Huang 2004)

Research studies in the past have focused on determining resilient modulus of different waste materials like demolition wastes (Perera et al. 2019), reclaimed asphalt pavement (RAP) materials (Puppala et al. 2011; Saride et al. 2015), recycled plastic granules (Arulrajah et al. 2017), tire derived aggregates (Arulrajah et al. 2019) to utilize them as a pavement material either as a base or subgrade material. The studies in the literature encourage the usage of different waste materials in pavement applications. One such waste material that is generated in large quantities across the world is fly ash. Owing to increased urbanization, production of thermal power energy generates lot of fly ash. In developing countries like India, the handling of waste materials is a challenging task. Ash ponds cover for more than 66,000 acres of land in India itself. With increasing usage of thermal power, it is estimated that fly ash will be stored in more than 1.8 million acres of land by 2032 (Bordolai and Sarmah 2010).

Central electricity authority (CEA) reports show that nearly 196 million metric tons of fly ash was generated for the year 2017 (CEA 2018) in India. Only 67% of the generated fly ash is being used. The major modes of utilization cover cement sector (25.6%), mine filling (6.4%), bricks and tiles (9%), reclamation of low-lying area (10.5%), ash dyke raising (6.9%), roads and flyovers (3.4%), etc. Fly ash in its fine form is used as a stabilizing agent in cement sectors (Sakai et al. 2005), and coarse fly ash is used as a fill material in retaining walls and embankments (Karnam Prabhakara et al. 2019; Kim et al. 2010).

Cementitious properties of fly ash with high amounts of CaO helps in stabilizing soils and increase the strength (Senol et al. 2006; Tastan et al. 2011). Edil et al. (2006) studied the effect of addition of self-cementing fly ash to the soil on its California bearing ratio (CBR) and resilient modulus values. They found the addition of fly ash to the soil increased the M_R values from 3-15 MPa for 0% fly ash, to 51-106 MPa for 18% fly ash addition. However, there are limited studies on the resilient modulus of the fly ash material alone.

The objective of the present study is to determining resilient modulus of fly ash. The effect of water content and time of curing on resilient modulus of the samples are also studied

2 Materials- fly ash

Fly ash used in the study was collected from Neyveli Lignite Corporation (NLC) Ltd., Neyveli, Tamilnadu. In general, fly ash captured in the electrostatic precipitators (ESP) are transferred to the silos and are collected in the dump trucks to the disposal pond. Fly ash used was collected directly in to air-tight containers from the silos. No loss of moisture content was ensured during transportation to the laboratory. Fly ash was finer in gradation and texture. Basic characterization tests like particle size distribution, specific gravity, morphology, chemical composition, compaction characteristics were performed on fly ash particles before commencing resilient modulus tests.

3 Experimental work

3.1 Particle size distribution and specific gravity

Fig. 2 presents the particle size distribution of the fly ash used in the present study. Sieve analysis on fly ash was conducted as per ASTM D 2487-98 (2000). Based on the gradation coefficients, fly ash was classified as poorly-graded sand type (C_c values ranged from 1 to 3, but C_u values was less than 6). The effective particle size (D_{10}) and average particle size (D_{50}) of fly ash were equal to 0.08 and 0.18, respectively. The specific gravity of fly ash was determined as per ASTM D854-10 and it was equal to 2.62. The specific gravity and particle-size distribution curve reported are an average of three trials.

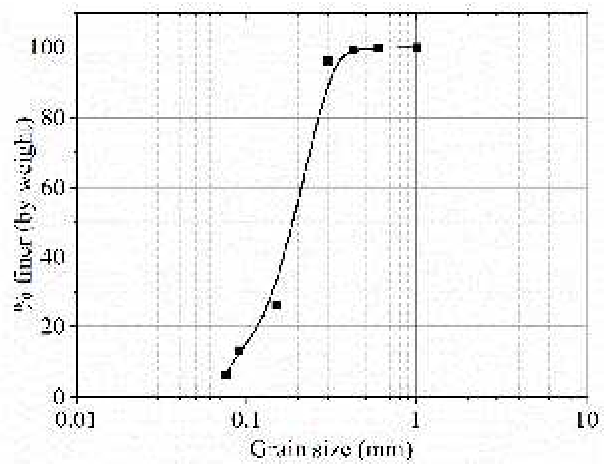
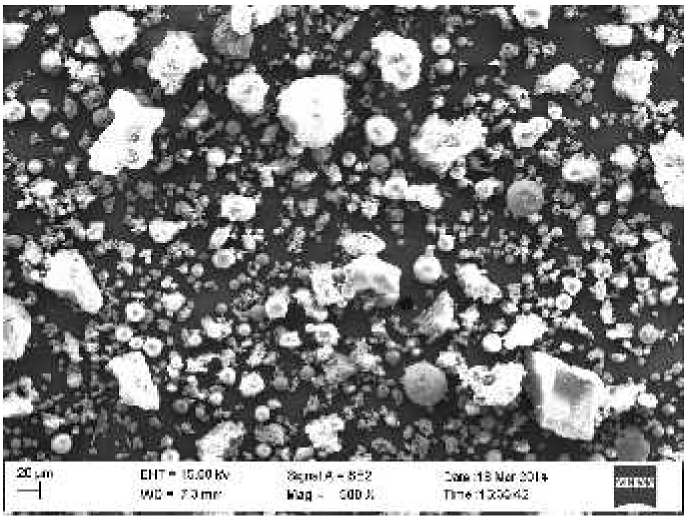


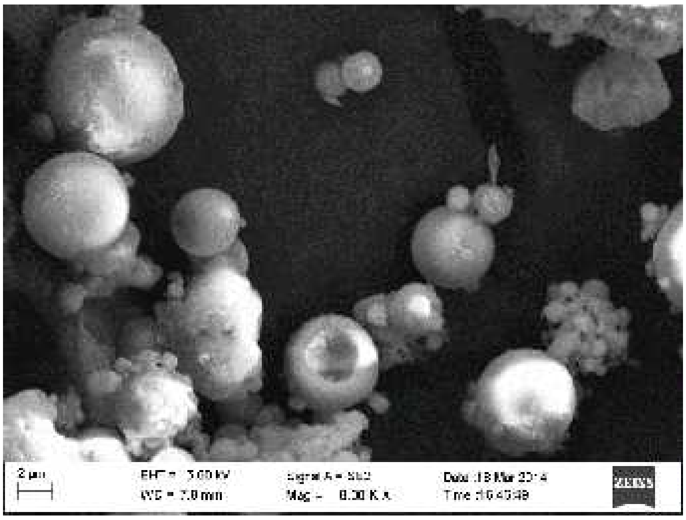
Fig. 2. Particle size distribution of fly ash

3.2 Morphological characteristics

Shape of the fly ash particles are studied under Scanning Electron Microscope (SEM). Due to non-conductive nature of fly ash particles, gold coating was done on their surface. This procedure produced a clear Scanning Electron Micrograph (SEM) image of the fly ash particles. Figs. 3 (a & b) presents the SEM images of fly ash at two different magnification factors equal to 500X and 8000X. High magnification factors were used to observe the exact shape of the particles. It could be clearly observed from Fig. 3(b) that fly ash particles are highly rounded in shape. Similar shapes for fly ash particles are observed by Kim et al. (2005).



(a)



(b)

Fig. 3. SEM images of fine fly ash at a magnification factor equal to (a) 500X and (b) 8000X

3.3 Chemical composition

Using X-ray fluorescence (XRF) spectrometer, the chemical compounds present in the fly ash are studied and Table 1 gives the chemical composition of fly ash by percentage of weight. The main compounds are Alumina Al_2O_3, Silica SiO_2 and CaO. High percentage of CaO helps fly ash to utilize as a stabilizing agent as it gets harder with the time. Fly ash used in the study is classified as Class C (CaO > 10%) in accordance with IS 3812, however, ASTM specifications mention CaO should be higher than 20% to classify a fly ash as Class C.

Table 1. Chemical composition of fly ash used in the study

Chemical compound	% (by weight)
MgO	1.85
Al_2O_3	32.34
SiO_2	40.6
CaO	11.9
K_2O	0.11
Fe_2O_3	9.6

3.4 Compaction characteristics

Standard proctor compaction was carried on fly ash in accordance with ASTM D698-12. The variation of dry unit weight of fly ash with the addition of water is presented in the Fig. 4. The maximum dry unit weight (MDD) and optimum water content (OMC) for fly ash were equal to 13.7 kN/m^3 and 26%, respectively.

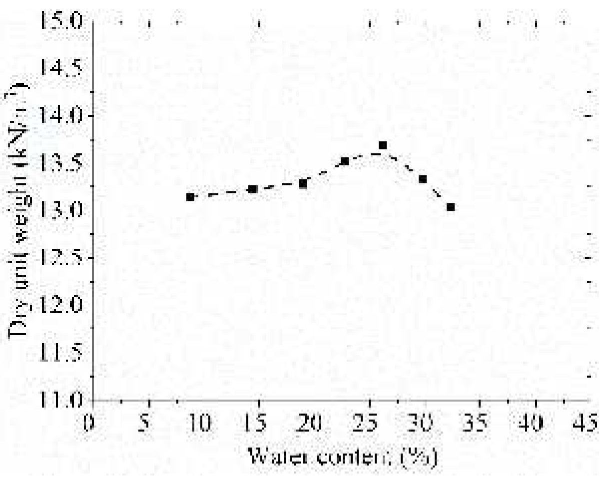


Fig. 4. Variation of dry unit weight with the water content

3.5 Resilient modulus tests

The resilient modulus testing was performed on fly ash samples prepared at three different water contents, optimum moisture content (OMC= 26%), wet side of optimum (OMC+2% = 28%) and dry side of optimum (OMC-2%= 24%). The samples were cured under water for two different curing periods, 6 hours and 24 hours. The corresponding relative compaction of the samples prepared was equal to 97% of the maximum dry unit weight, satisfying the IRC specification for subgrade preparation.

Cyclic triaxial apparatus was used to determine the resilient modulus of all the fly ash samples. The main parts of the apparatus include cyclic triaxial cell actuator, air and water control valves, overhead water tank and the monitoring system. Fig. 5 shows the different parts in the cyclic triaxial cell, like confining pressure chamber, specimen and the actuator.

The sequence of steps followed in the resilient modulus testing include: specimen preparation, assembling of triaxial cell, application of confining pressure, stress conditioning, stress application through 15 additional stress states. The following sequence of steps were followed for all the samples tested in the study.

Sample preparation

All the samples tested in the study are prepared in split moulds of dimensions, 100 mm in diameter and 200 mm in height. The fly ash samples were added with the water corresponding to pre-decided water contents and mixed homogenously. An aluminum foil was placed around split mold such that the sample did not stick to the surfaces of the split mould. After placing the aluminum foil, both the halves of the split mould were attached using the screws. The compaction was carried in three layers and energy equivalent to standard Proctor was applied. The compacted samples were left to curing for 6 hours and 24 hours.

Conditioning and loading

The cured samples were placed in the cyclic triaxial cell with a rubber membrane around it, to avoid the direct contact of water on the sample. Cyclic triaxial cell was filled with the water to apply uniform confining pressure in all direction on the sample. Later, samples were subjected to 500 conditioning cycles and 15 different stress states (five deviatoric stresses and three confining stresses). Details of load and deformation were collected during all 15 cycles over the entire sequence of application of stress state, however, the last five applications of stress state were considered for the calculation of resilient modulus. Table 2 gives the different deviatoric stresses and confining stresses considered in the study. A constant confining stresses were maintained constant for every five cycles. The deviatoric stress applied was constant for cycles 1 to 5, 6 to 10, and 11 to 15. The application of stresses was carried in accordance with AASHTO-T307.

Table 2. Resilient modulus testing sequence for a subgrade material.

Cycles	Deviatoric stress (kPa)	Confining Stress (kPa)
1	12.5	41.4
2	24.9	41.4
3	37.3	41.4
4	49.6	41.4
5	61.9	41.4
6	12.2	27.6
7	24.7	27.6
8	37.2	27.6
9	49.5	27.6
10	61.7	27.6
11	12.3	13.8
12	24.6	13.8
13	37.1	13.8
14	49.5	13.8
15	61.8	13.8

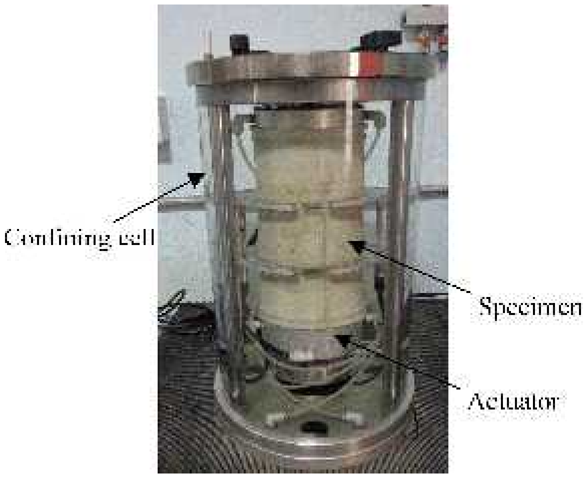
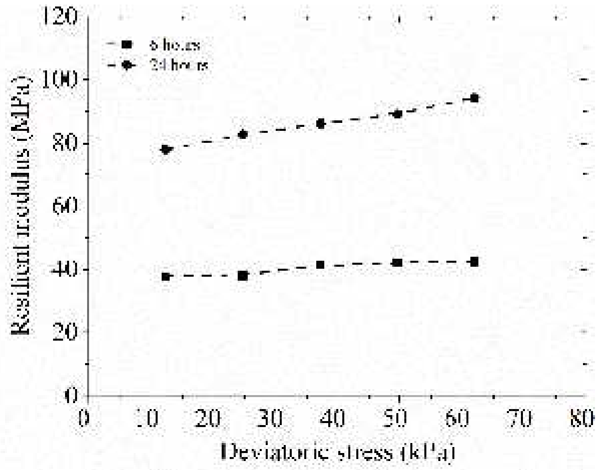


Fig. 5. Cyclic triaxial cell

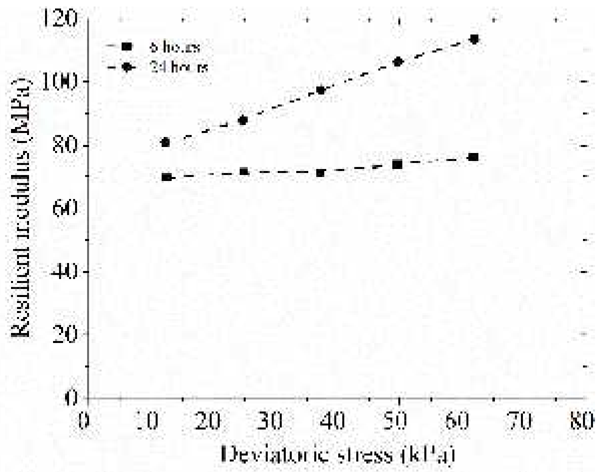
Results and discussion

Figs. 6 (a, b & c) show the resilient modulus values for the fly ash samples prepared with different water contents equal 24%, 26%, and 28%. The resilient modulus of fly ash samples with curing period of 24 hours was found to be higher than that of samples with six hours curing period. The pattern was found similar at all the water contents tested. This behavior could be attributed to the pozzolanic reaction of fly ash that takes place with the passage of time. Similar behavior was observed for red silty clay till mixed with 18% fly ash (Edil et al. 2006), reclaimed asphalt pavement (RAP) mixed with fly ash (Saride et al. 2015). For curing period equal to six hours, the resilient modulus values of samples prepared with 24%, 26% and 28% water contents ranged from 30 to 80 MPa, whereas for 24 hours of curing, the M_R value ranged from 75 to 120 MPa for samples prepared with 24%, 26% and 28% water contents. High values of M_R ranging between 220-550 MPa for RAP and fly ash mixtures (Saride et al. 2015), and 87-205 MPa for crushed brick-plastic granules and RAP-plastic granules mixtures (Arulrajah et al. 2017) were reported in literature. The difference in the resilient modulus mainly depends on the type of the material used and the deviatoric stress applied on the sample.



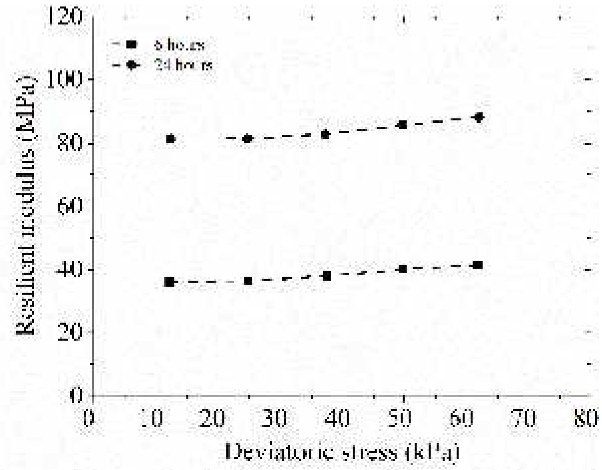
6 hours
24 hours
Resilient modulus (MPa)
Deviatoric stress (kPa)

(a)



6 hours
24 hours
Resilient modulus (MPa)
Deviatoric stress (kPa)

(b)



(c)

Fig. 6. Resilient modulus test results of fly ash alone at (a) 24% water content, (b) 26% water content, and (c) 28% water content

In order to study the effect of water content on the resilient modulus, histograms of M_R values corresponding to curing periods of 6 hours and 24 hours were plotted for different water contents (see Fig. 7). For samples with 6 hours and 24 hours curing time, the resilient modulus values at OMC were found to be considerably higher than that of samples prepared at dry or wet side of OMC. The trend highlights that water content significantly affects the strength and stiffness of the samples.

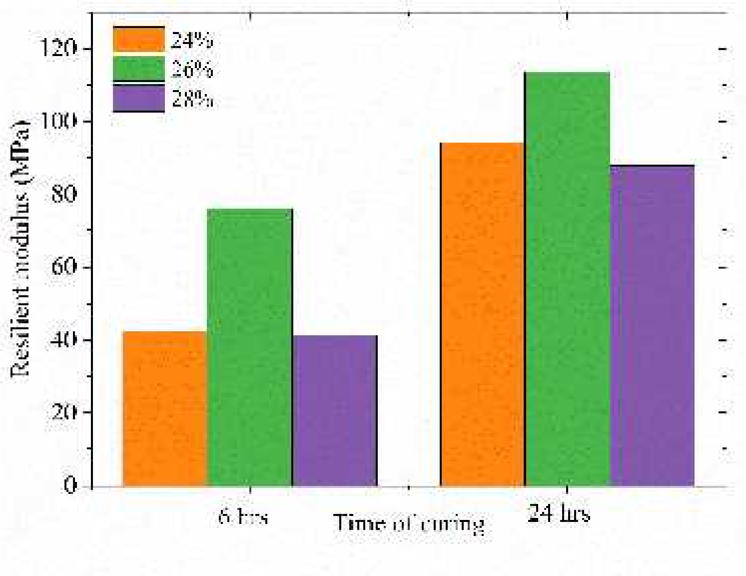


Fig. 7. Histograms of resilient modulus values for various curing times and water contents of fine fly ash

4 Conclusions

In this study, effect of the water content and the curing period were studied on fly ash collected from Neyveli thermal power plant, Neyveli, Tamilnadu. The following conclusions are derived from the study

1. Resilient modulus (M_R) of fly ash samples with curing period of 24 hours was found to be 30-50% higher than that of samples with 6 hours curing period.
2. The resilient modulus (M_R) values of fly ash samples prepared at OMC were found to be higher than that of those of samples prepared at dry or wet sides of OMC by 44% and 45%, and 17% and 22% corresponding to curing periods of 6 hours and 24 hours, respectively.

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