Resilient Modulus Studies on Fly Ash and Granulated Rubber Composites

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Abstract: In the fast-growing world, solid waste management is one of the key aspects to be considered for a sustainable environment. In the present study, two solid wastes, namely, fly ash and rubber wastes are considered and studied to evaluate the feasibility of utilizing this waste composite as a fill material in earth structures. Resilient modulus of the material is one of the essential design parameters to design pavements over such fill material. Two percentages of granulated rubber of nominal size equal to 9.5 mm is added to fly ash and the resilient modulus of the composite material is determined from cyclic triaxial tests. The effect of curing period and water content is also investigated by resilient modulus testing on samples prepared at optimum moisture content (OMC%), and OMC±2% (wet and dry side of optimum) and cured for two periods, viz., 6 hours and 24 hours. The resilient modulus is found to increase with the curing period with the highest values recorded for samples prepared at OMC. The resilient modulus for fly ash-granulated rubber composite at OMC after 24 hours of curing period ranges between 37-114 MPa.

Keywords: Resilient modulus; granulated rubber; cyclic triaxial; retaining wall.

1 Introduction

Scrap tires and fly ash are two industrial wastes that are being generated in large volumes in India. Disposal of these wastes is highly challenging in conditions like India. Scrap tires are in general non-biodegradable and can be severe environmental menace. Nearly 263 million scrap tires were generated in USA during 2019 (U. S. Tire Manufacturers Association 2020), 3.29 million metric tons of end-of-tires generated in Europe in 2016 (Rubber News 2018), 90 million tires in Japan in 2020 (JATMA, 2021) and India discards 275,000 tyres everyday (Agarwal 2019). Properties like lightweight, free draining, and thermally resistive, makes tire wastes a favorable material to use in geotechnical applications.

On the other side, management of coal ash generating from around 202 thermal power stations as per Central Electricity Authority (CEA 2021) report is a challenging task. Indian coal has high ash content (~45%) in comparison to other imported coals which have low ash content (10-15%). The amount of fly ash generated in the year 2020-2021 is nearly 232.5 million tons (Central Electricity Authority, 2021). Fly ash has been utilized in various sectors like cement (25.8%), roads and flyovers (15.0%), bricks and tiles (12.9%), mine filling (6.2%), and ash dyke raising (7.9%). There has been a significant increase in the percentage of utilization of fly ash in roads and flyovers from 3.4% in 2018 (CEA 2018) to 15.0% in 2021. This increase is mainly because of the usage of fly ash as a subgrade material in embankments or as a backfill material in retaining walls, as they generally consume large volumes.

In the present study, an attempt was made to study the feasibility of using the mixture of fly ash and rubber wastes as a subgrade for a pavement system. The response to repeated loads on the subgrade material was studied by evaluating the resilient modulus (M_r) of the samples composed of mixtures of fly ash and rubber wastes.

Resilient modulus, M_r is defined as the elastic modulus based on the recoverable strain under repeated loading (see Fig. 1).

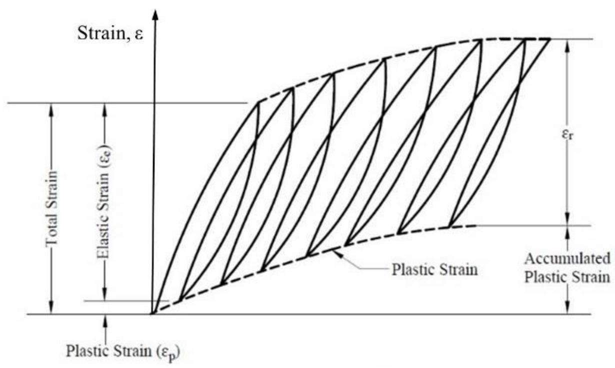


Fig. 1. Variation of strain for the repeated load application (modified after Huang 2004).

There have been many studies on using different wastes as a pavement material like recycled plastic granules and demolition wastes (Arulrajah et al. 2017; Perera et al. 2019), recycled construction and demolition wastes (Arulrajah et al. 2013), fly ash treated reclaimed asphalt pavement (Saride et al. 2015), spent coffee grounds and recycled glass geopolymers (Arulrajah et al. 2019). On the other side, there are studies on shredded tires mixed with sand and widely used as an embankment fill material (Balunaini et al. 2014; Balunaini and Prezzi 2010; Pincus et al. 1994). However, there are no studies available on utilization of fly ash-rubber wastes mixtures as a pavement material. In this study, a composite material of rubber wastes and fly ash is proposed. Accordingly, experimental testing program relevant for design of embankments constructed over or with fly ash-rubber wastes mixtures were undertaken.

The resilient modulus values were determined by conducting cyclic triaxial tests on various mixtures of fine fly ash and tire chips (10% and 30% by dry weight of fly ash) as per AASHTO code T307-99(2003). The M_r tests were conducted at OMC, and Wet and dry sides of OMC (±2%) and at different hours of curing periods (6 hours and 24 hours).

2 Materials

2.1 Fly ash

Fly ash was collected directly from the silos of Neyveli Lignite Corporation (NLC), Neyveli, Tamilnadu, and was shipped directly to IIT Hyderabad laboratories in air-tight barrels. Hereafter, fly ash is termed as FA.

2.2 Granulated rubber

Shredded rubber tires with a nominal size of 9.5 mm are called as granulated rubber as per ASTM D6720 (ASTM 2012a). Figure 2 shows the photograph of the granulated rubber used in the present study. Henceforth, the granulated rubber is designated as GR.

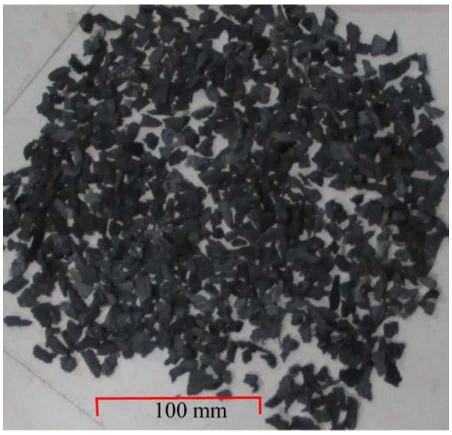


Fig. 2. Photograph of granulated rubber

3 Experimental work

The testing program comprised of basic characterization tests that covers particle-size distribution, morphological characteristics, specific gravity, chemical composition, compaction characteristics, followed with resilient modulus tests.

3.1 Particle-size analysis

Figure 3 shows the particle-size distribution of fly ash and granulated rubber. Dry sieve analysis was conducted for both fly ash and granulated rubber as per ASTM D2487 (ASTM 2000). Specific gravity for fly ash and granulated rubber was determined in accordance with ASTM D854 (ASTM 2010) and ASTM C127 (ASTM 2004), respectively.

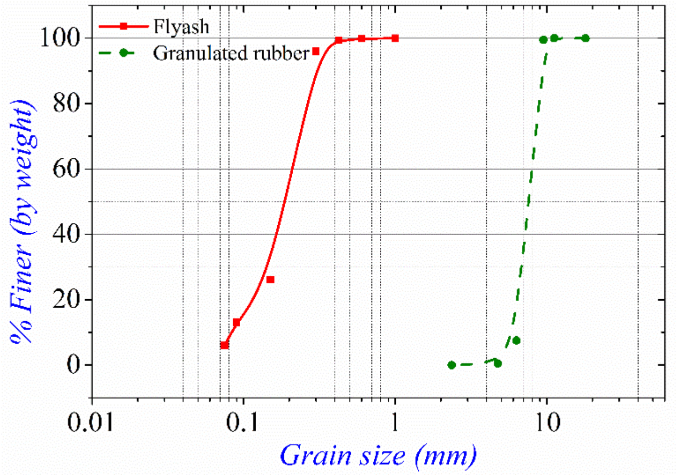


Fig. 3**.** Particle size distribution of FA and GR

Table 1 presents the gradation coefficients of fly ash and GR. They were classified as poorly-graded sand type (SP), and poorly-graded gravel type (GP), respectively.

Table 1. Gradation characteristics of FA and GR

Property	Unit	Value	
		Fly ash	GR
D_{10}	mm	0.08	6.0
D_{50}	mm	0.20	7.0
C_u	-	2.66	1.27
C_c	-	1.34	0.96
Soil classification	-	SP	GP
Specific gravity, G	-	2.62	1.16

3.2 Morphological studies

Morphology of the fine fly ash particles was investigated using Scanning Electron Microscope (SEM) and they were found to be spherical in shape. The images were zoomed in to a magnification factor of 10,000 X (Fig. 4).

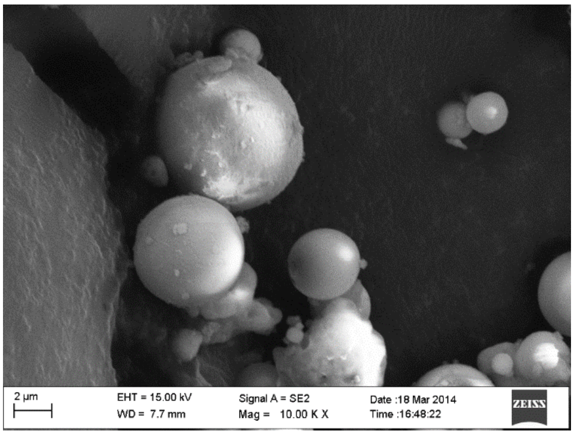


Fig. 4. SEM image of FA at 10,000 X magnification

3.3 Chemical composition

Oxide percentages of different elements in FA were determined using X-ray fluorescence (XRF) spectrometer. The main constituents included Alumina Al_2O_3 (~32.3%), Silica SiO_2 (~40.6%), and Calcium Oxide CaO (~11.9%). More details on chemical composition can be found in Karnamprabhakara et al. (2021).

3.4 Compaction results

In accordance with ASTM D698-12, standard Proctor compaction was carried out on fly ash and fly ash-GR mixtures. Figure 5 presents the variation in dry unit weight of FA-GR mixtures with the addition of water. The water content of the mixture sample was determined as the ratio of weight of water present in the mixture to that of the dry weight of fly ash alone, but not with respect to the dry weight of fly ash and granulated rubber. The optimum moisture content (OMC) for fly ash was found to be 26%. The OMC decreased to 22.5% to 23.2% with the addition of tire chips in the mixture. The maximum dry density (MDD) of FA alone was found to be 13.7 kN/m^3 and MDD decreased to 12.4 kN/m^3 when granulated rubber was added to fly ash, considering difference in the specific gravities. Among the various mixtures of FA and GR tested; 30% addition of GR showed the lowest MDD value of 12.4 kN/m^3. Table 2 presents the OMC and MDD for the FA-GR mixtures used in the present study.

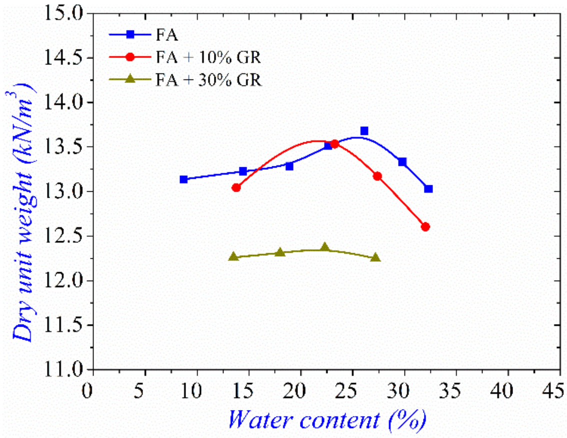


Fig. 5. Compaction curve for FA-GR mixtures under Standard Proctor energy

Table 2. Compaction characteristics of mixtures of FA and GR

Property	Unit	0% GR	10% GR	30% GR
Dry unit weight	kN/m^3	13.7	13.5	12.4
Optimum moisture content	%	26.0	23.3	22.3

3.5 Resilient modulus (M_r) testing

The M_r tests were conducted on FA-GR mixtures prepared at water contents, equal to OMC (= 26%), wet and dry sides of optimum (OMC±2% =24%, and 28%). Two curing periods, viz., 6 hours and 24 hours, were considered for studying the effect of curing. Cyclic triaxial testing was carried out to determine the resilient modulus of the FA-GR mixtures. More details of the equipment can be found in Karnamprabhakara et al. (2021).

The following steps were considered for the resilient modulus testing:

i. Specimen preparation
ii. Triaxial assembling
iii. Stress conditioning, and
iv. Application of stress through 15 additional stress states

Sample preparation

FA and FA-GR mixture samples were prepared in a split mould of dimensions 100 mm in diameter and 200 mm in height. For FA-GR mixtures, fly ash was initially added with the desired water content and then added the granulated rubber. Fly ash and granulated rubber was thoroughly mixed, and the mixture was placed in three layers in the split mould and equivalent standard Proctor energy was imparted on each layer.

The prepared samples were then left for 6 hours and 24 hours curing, before testing.

Triaxial assembly

The cured and intact samples were placed on the bottom pedestal, and the pore pressure and back pressure connections were made. The actuator was moved such that the top pedestal touches the reaction frame, and then the platen vacuum was applied for firm locking. Once the sample is fixed the triaxial cell was placed in position. Linear variable differential transducer (LVDT) was placed to measure the axial deformation of the sam- ple.

Stress conditioning

The triaxial chamber was filled with water and then the confining pressure was applied on all sides of the sample. Stress conditioning was done in order to eliminate the effect of disturbance caused during the specimen preparation procedures. It also helps in minimizing the imperfect contact between the top pedestal and the specimen. In this study, conditioning cycles were limited to 500 since the decrease in specimen height has ceased by then.

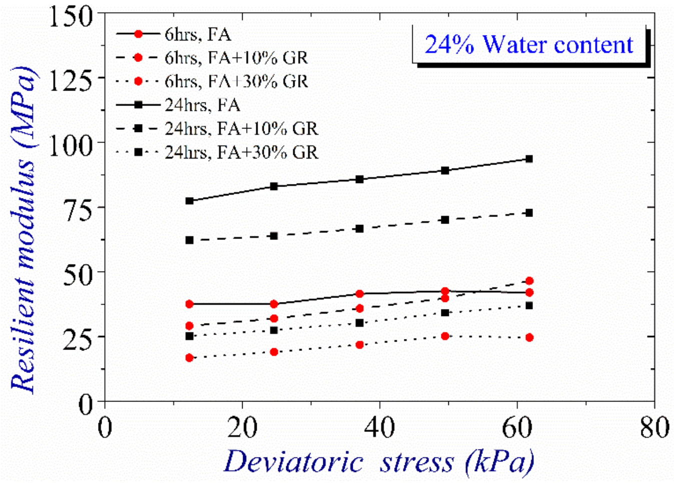
Stress application through 15 additional stress states

After the conditioning cycles, stresses were applied on the sample through fifteen additional stress states. The stresses were applied in fifteen cycles as per the AASHTO code T307-99(2003). The load was applied for 0.1 seconds followed with a rest period of 0.9 seconds. Stress application and load sequence were detailed in Karnamprabhakara et al. (2021) for the determination of resilient modulus for fly ash alone.

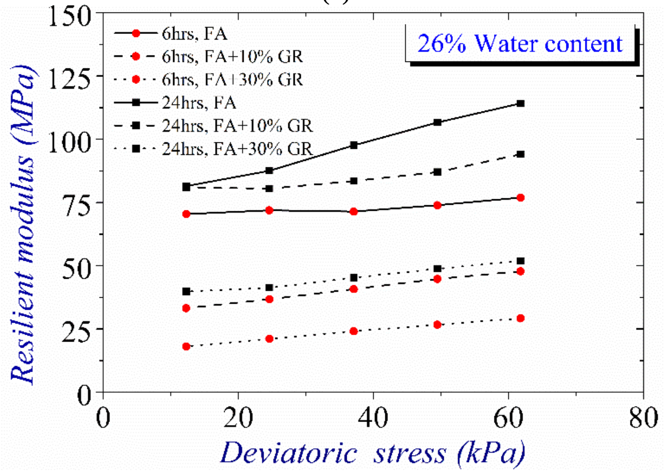
4 Results and discussion

The following sections discusses the resilient modulus values obtained for the FA, and FA-GR mixtures from the cyclic triaxial testing. The effect of curing, water content and the deviatoric stress were discussed. The last five cycles of stress states were used in the calculation of resilient modulus.

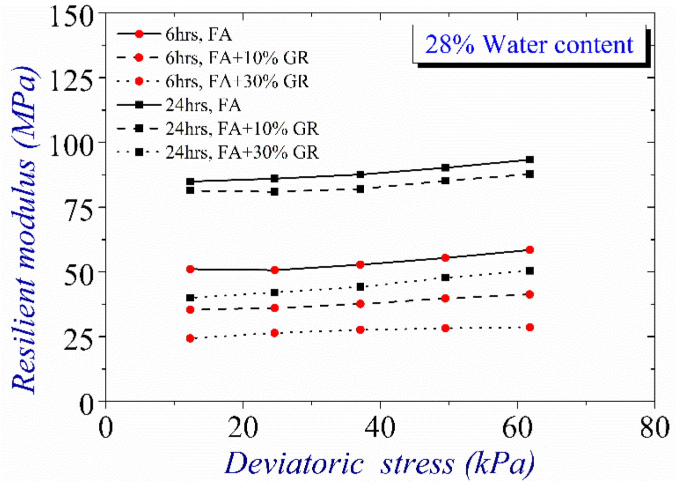
Figures 6(a), (b), and (c) show the variation of resilient modulus values with deviatoric stress for all the mix proportions considered in the study for different curing periods and prepared at water contents equal to 24%, 26% and 28%. An increase in the resilient modulus was observed with the increase in the deviatoric stress for the range of deviatoric stress considered in the study. This trend is consistent for all the mixtures used in the study. From the Figure 6, it can also be concluded that the resilient modulus values decrease with the increase in the percentage of granulated rubber. The resilient modulus for 10% addition of granulated rubber to fly ash is lower than that fly ash alone, and the resilient modulus value for 30% addition of granulated rubber is lower than that of 10% addition of granulated rubber. For example, at a deviatoric stress equal to 62 kPa for 24 hours curing period and water content of 24%, M_R decreased by 22.1% with 10% addition of tire chips to fly ash compared to that of only fly ash, and M_R value of 30% tire chips addition decreased by 48% compared to that of 10% tire chips. This decrease in the resilient modulus with increase in percentage of granulated rubber was observed for all the water contents considered. The decrease in the resilient modulus was mainly because of the rebound ability of tire chips. Similar observations were made for sand-tire chips mixtures (Pincus et al. 1994).Though small proportions of tire chips(up to 30%) are added to fly ash, they occupy large volume in the mixture due to rela- tively much lower specific gravity of tire chips compared to that of fly ash. The resilient modulus for 30% addition of tire chips was in the range of 25 to 40 MPa, much less than that compared to that of fly ash (M_R ranges from 70 to 120 MPa), and other mate-rials like coffee spent grounds and recycled glass geopolymers (Arulrajah et al. 2019), and construction wastes (Arulrajah et al. 2013) and so on. However, this composite material can be recommended for subgrade of a pavement system for low-volume roads.



(a)



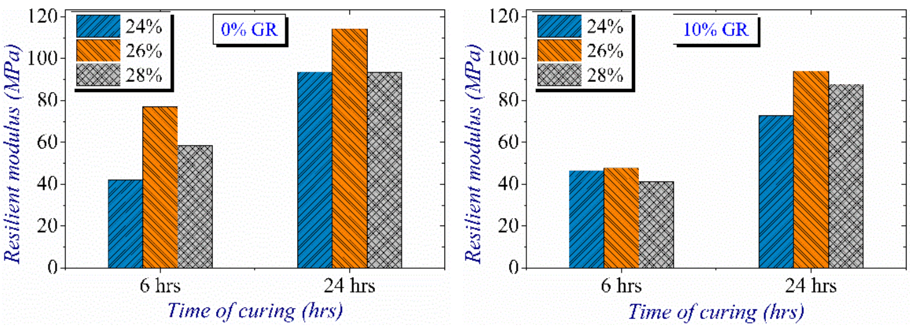
(b)



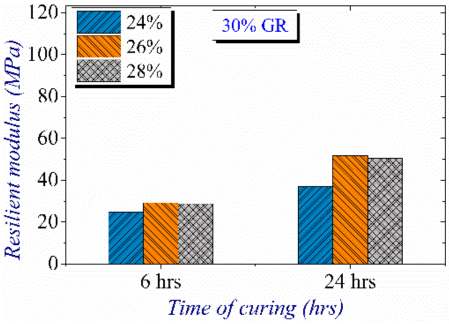
(c)

Fig. 6. Resilient modulus tests results of different mixtures prepared at water contents equal to (a) 24% (b) 26% and (c) 28%

The effect of water content on the resilient modulus of FA-GR mixtures was studied using histograms of M_R values for curing periods of 6 hours and 24 hours, for three different water contents considered (Figures 7a, b, c). It could be observed that the effect of water content was significant in all the three mixtures studied. The samples prepared at optimum moisture content showed the maximum resilient modulus for all the FA-GR mixtures. From Figure 7, it was also observed that the resilient modulus value for samples prepared at water content equal to 26% (OMC) and curing period of 24 hours was higher than that of samples prepared with water contents equal to 24% and 28% indicating that the resilient modulus of fly ash is higher at its OMC after 24 hours of curing. For curing period equal to 6 hours, water content did not have a significant effect on the resilient modulus. This trend was followed for FA alone and FA-GR mixtures.



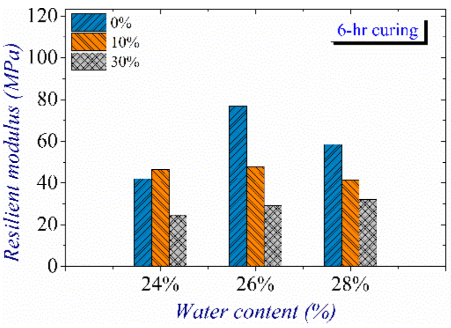
(a) **(b)**



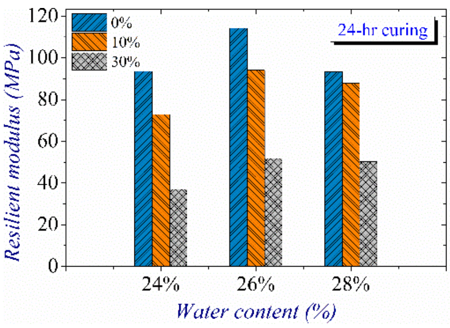
(c)

Fig. 7. Resilient modulus values corresponding to different cases at different water contents and after 6- and 24-hours curing periods (a) 0% GR (only FA), (b) FA+10% GR and (c) FA+30% GR

In order to study the effect of addition of tire chips on resilient modulus values, histograms of resilient modulus values were plotted for various percentages of granulated rubber in the mixture for two curing periods considered. Figures 8(a) and (b) present the effect of rubber content on the resilient modulus at 6 hours and 24 hours, respectively. As discussed under the Figure 6, it was clearly observed that the resilient modulus decreases with the increase in the percentage of rubber after 6-hour and 24-hour curing periods.



(a)



(b)

Fig. 8. Resilient modulus vs. water content at curing periods of (a) 6 hours and (b) 24 hours

5 Conclusions

Fly ash added with 10% and 30% of granulated rubber (by weight of fly ash) were tested for compaction characteristics and resilient modulus values. The following are the major conclusions from the study,

i. The maximum dry unit weight (MDD) decreases with the increase in the granulated rubber content. The MDD of FA-GR mixture with 30% GR was equal to 12.4 kN/m^3 compared to 13.7 kN/m^3 for fly ash alone.

ii. Resilient modulus (M_R) values of FA-GR samples with curing period of 24 hours were higher than those with a curing period of 6 hours. The trend was same for both the 10% and 30% mixtures. However, M_R values of FA-GR were all lesser than FA alone.

iii. Resilient modulus (M_R) values of FA-GR samples prepared at optimum moisture content (~26%) were higher than the samples prepared at dry (~24%) and wet of optimum (~28%). The M_R values FA-GR mixtures ranged after 24 hours of curing at three different water contents considered in the study ranged between 37 and 114 MPa.

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