Compressibility and deformation studies of compacted fly ash /GGBS mixtures

Anil Kumar Sharma* / primary author
Amrita University, Coimbatore, India
**Formerly Research Scholar, Indian Institute of Science, Bangalore, India, sharma.kr.anil@gmail.com*

P.V. Sivapullaiah, Co-Author
Indian Institute of Science, Bangalore, India

ABSTRACT

Utilization of industrial wastes that involves the bulk utilization such as embankments, structural fill, construction of roads etc. could not only help in reducing disposal problems but also provides a solution to conserve natural materials like soil. But due to lack of pozzolanic reactivity of certain industrial wastes such as fly ash, these materials remain underutilized. It is advantageous to use a combination of different industrial wastes materials rather than using individually. This paper presents the results of compressibility and deformation characteristics of mixtures of fly ash and ground granulated blast furnace slag (GGBS) mixtures at different proportions. By comparing the compressibility behaviour of fly ash and GGBS between conventional 24 hour and 30 minutes duration of load increment, it was found that 30 minutes was sufficient to assess the compressibility characteristics due to the higher rate of consolidation of such materials. It is observed that the compressibility of the fly ash/GGBS mixtures slightly decreases initially but increase with increase in GGBS content. Addition of lime did not have any significant effect on the compressibility characteristics since the pozzolanic reaction, which is a time dependent process and as such could not influence due to very low duration of loading. The cyclic behaviour holds importance as it will show its potential to perform under traffic loads. Repeated load triaxial test has been carried out on fly ash/GGBS mixture for optimum proportion to study the variation in resilient modulus and accumulation of plastic strain with number of load cycles. The higher resilient modulus values indicated its suitability for use as sub-grade or sub-base materials in pavement construction. Permanent axial strain was found to increase with the number of load cycles. Test results indicate the suitability of fly ash/GGBS mixture for utilization in embankments, structural fills, road construction etc.

Keywords: fly ash, GGBS, pozzolanic materials, compressibility, embankments.

1 INTRODUCTION

A variety of industrial waste materials are produced from many industrial activities in India (Pappu et al., 2007). The excess production of these waste materials due to industrialization and urbanization is the main cause behind environmental pollution. Also, the non-renewable resources are degrading day-by-day because of the increase in demand of raw materials for the industrial activities. Efforts are being made to counter these problems arising out of disposal of the industrial wastes. Recycling these industrial wastes for various beneficial uses would control the environmental problems (Dondi et al., 1997).

The major contributors of industrial solid wastes in India are the thermal power plants producing fly ash and Iron and Steel industries producing blast furnace slag (Singh and Garg, 1999). Fly ash and ground granulated blast furnace slags (GGBS) are well-known pozzolanic industrial by-products that are used in many civil engineering applications such as in blended cements, concretes etc (Puertas et al., 2000). Uses of these materials in manufacture of concrete, brick making, soil-stabilization treatment covers only a small percentage of the total production. Hence more emphasis is needed in those applications that require bulk utilization such as in embankments, structural earth fills, road sub-grades etc.

Proper assessment and evaluation of industrial waste materials such as fly ash, GGBS etc. should be done for safe and economical utilization. If these materials have to be used as sub-base, sub-grade or as embankment material, one has to check its compressibility characteristics as well as its performance under cyclic load. Estimation of consolidation settlement is important for geotechnical design engineers to ensure no damage or decrease in the serviceability of the structure occurs. Although a lot of compressibility studies have been carried out on fly ash for utilization in embankments, sub-grades etc. (Kaniraj and Gayathri, 2004; Mishra and Das, 2012; Tu et al., 2007), but studies on mixtures of fly ash and GGBS have not been studied so far. This present study shows the investigation on the consolidation and deformation characteristics of fly ash/GGBS mixtures at different proportions to predict its competency in taking the load from any structures to be built on the embankments, pavements or structural fills that are constructed with these materials.

2 MATERIALS AND METHODOLOGY

2.1 Materials

Fly ash was collected from Raichur thermal power plant which is in Raichur district of Karnataka state, India. GGBS was obtained from Larsen & Toubro ready concrete mix plant in Bangalore where it is used as partial replacement for cement in concrete. The physical properties of fly ash and GGBS are given in Table 1. From the particle size distribution data; it is seen that that GGBS consists of entirely silt-sized particles whereas fly ash has particles in range between sand and silt. SEM images of fly ash and GGBS are shown in Figures 1 and 2 respectively. Fly ash consists of spherical shaped particles as seen from the SEM image. The SEM micrograph of GGBS shows that particles have angular shape and sharp edges.

Table 1 Physical properties of fly ash and GGBS

Properties	**Materials**	
	fly ash	**GGBS**
Specific gravity	2.15	2.84
Sand fraction (%)	24	-
Silt fraction (%)	74	99.7
Clay fraction (%)	2	0.3
Liquid limit (%)	32	40
Plastic limit (%)	Non-Plastic	Non-Plastic
Plasticity index (%)	Non-Plastic	Non-Plastic

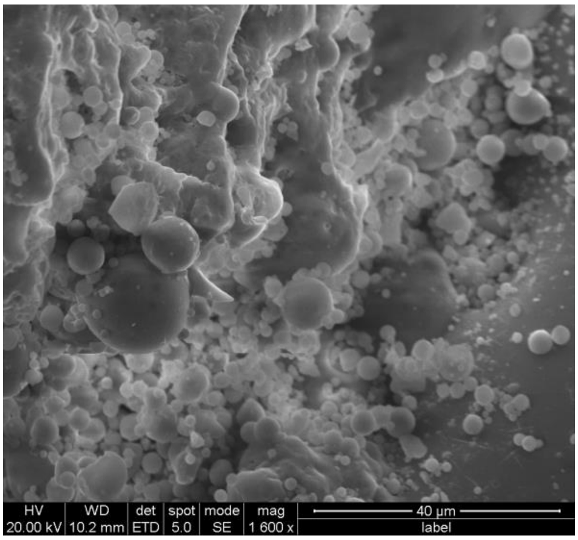

Figure 1 SEM image of fly ash

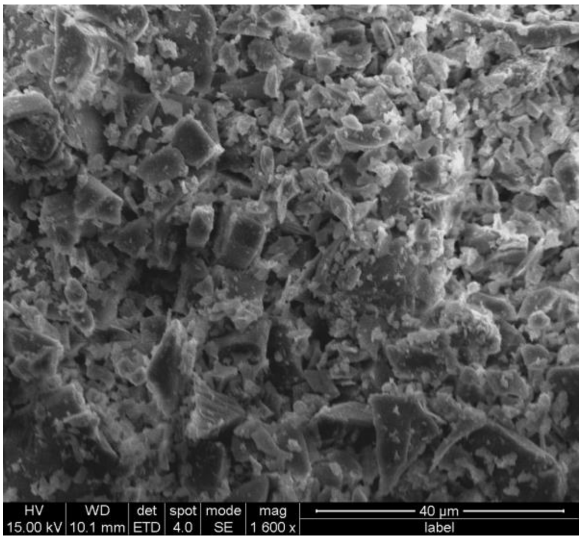

Figure 1 SEM image of GGBS

2.2 Methodology

The compressibility characteristics of the Fly ash-GGBS mixture at different mixing ratios were determined using oedometer tests as per IS: 2720 (part-15) (1986). The GGBS content varied from 10% to 40% of the dry weight of the mix. The samples were prepared at optimum conditions of the mixture which were obtained from mini compaction test developed by Sridharan and Sivapullaiah (2005).

This section provides the methodology adopted in this present study. The compressibility tests were carried with 30 minutes as duration of load increment since pozzolanic materials like fly ash, GGBS are non-plastic materials and the consolidation process is very fast in these materials. Adopting this methodology could save a lot of time and effort for the experiments. Since fly ash and GGBS are pozzolanic materials and usually require initial chemical activation, hence effect of small amount of lime on the compressibility characteristics is also tried.

The cyclic behaviour of these materials holds importance as it will show its potential to perform under traffic loads. Repeated load triaxial (RLT) test has been carried out on fly ash/GGBS mixture for optimum proportion (70:30) to study the variation in resilient modulus and accumulation of plastic strain with number of load cycles. RLT test is capable of creating dynamic loading conditions similar to pavements. It is currently the most common method to determine the resilient modulus and plastic deformation characteristics of sub-grade soils and unbound aggregates in the laboratory. The repeated load triaxial apparatus for studying the mechanical behaviour has been carried only for the sample containing fly ash and GGBS in the ratio 70:30. The dimensions of the specimen tested were having a diameter of 38 mm and a height of 76 mm. Haversine-shaped load form was applied on the sample at a frequency of 1 Hz upto 1000 cycles. The test was carried out at consolidated-undrained (CU) conditions.

3 RESULTS AND DISCUSSIONS

3.1 Compressibility tests

The stress-strain curves from oedometer test of fly ash-GGBS mixtures are shown in Figure 3. In these figures, symbols FA and GGBS have been used to denote fly ash and ground granulated blast furnace slag respectively. The numbers appearing before each symbol are their respective weight percentages. For example, the sample 80FA20GGBS means fly-GGBS mixture with 80% fly ash and 20% GGBS. It is observed that pure GGBS specimen is more compressible than pure fly ash sample. Since GGBS particles are smaller fly ash, the chances of particle slippage and rearrangement would be more (Rodriguez, 2013). Also the shape of the GGBS particles is angular which makes it more compressible than spherical fly ash particles. However with increase in GGBS content the gradation of the mixture changes from poorly to well-graded and the mixture becomes less compressible. The strain level experienced by the fly ash-GGBS mixtures decreases with increase in GGBS content. It means that the resistance to deformation in the mixtures increases with GGBS content. This may due to the increase in the density of the mixtures with GGBS content. Similar compressibility behaviour is found when 2% lime is added to the fly ash/GGBS mixtures (Figure 4).

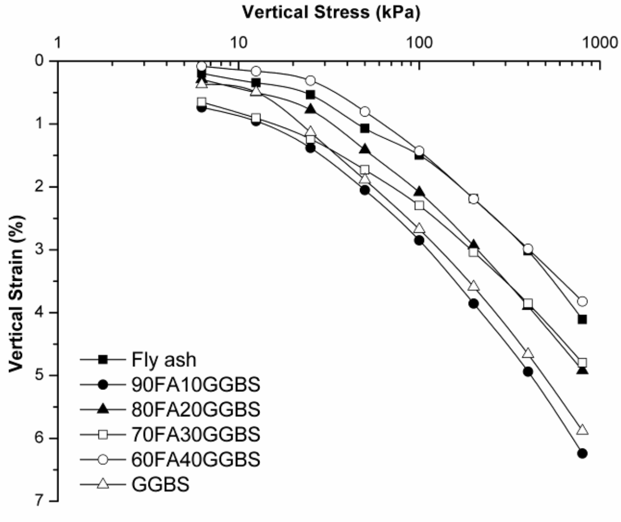

Figure 3 One-dimensional compression curves of fly ash-GGBS mixtures without lime

Since the compressibility tests are completed within a day after the start of the test, the chances of binding of the particles due to pozzolanic reactions are very less. if the test had been conducted at 24 hour load increment duration, addition of lime would have predominant effect on the compressibility characteristics. in this case also, at higher percentage of ggbs, the mixture becomes well packed and shows lower compressibility.

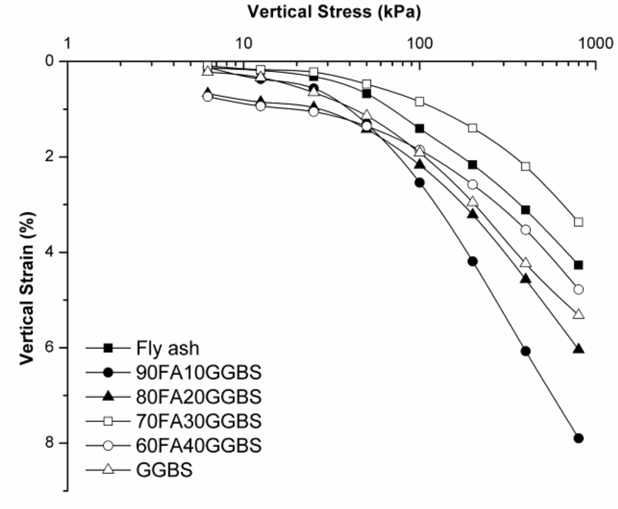

Figure 4 One-dimensional compression curves of fly ash-GGBS mixtures with 2% lime

3.2 Resilient Modulus

The test results show the variation of resilient modulus with number of cycles for 50 kPa confining pressure (Figure 5). The variation in the resilient modulus behaviour with the number of cycles is similar to other studies (Gabr et al., 2013). It is seen that the resilient modulus is more or less constant initially but decreases at higher number of cycles.

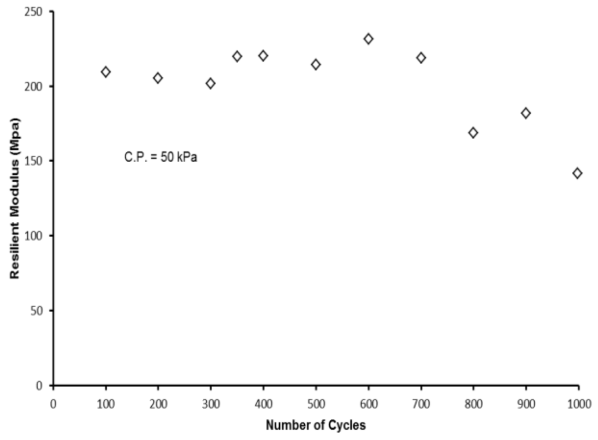

Figure 5 Resilient modulus versus no. of cycles (50 kPa)

At low confining pressure, the failure of the specimen would have resulted in the decrease of the resilient modulus values. The average resilient modulus value was found to be 200 MPa, which is typically good for its utilization in the sub-base and sub-grade materials. At higher confining pressures the variation in the resilient modulus is more or less constant up to 1000 cycles but did not show any sign of failure (Figures 6 and 7). Several studies have shown that morphological properties of the materials like shape, angularity etc. have a significant impact on its performance (Araya, 2011). In general, materials with angular shapes and rough surfaces increase the strength and stiffness of the pavements. Hence addition of GGBS, which are angular particles, may enhance the stiffness properties like resilient modulus when used as sub-grade materials.

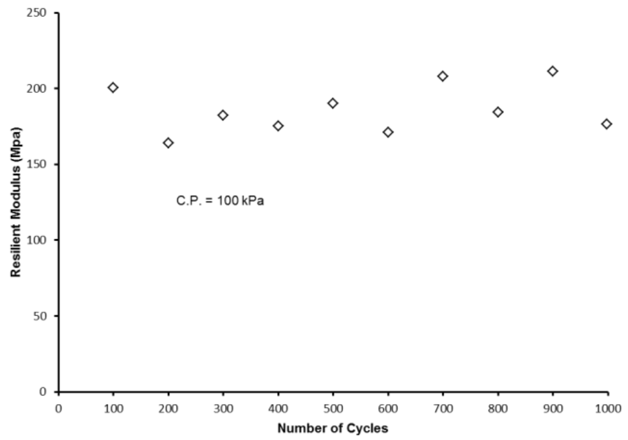

Figure 6 Resilient modulus versus no. of cycles (100 kPa)

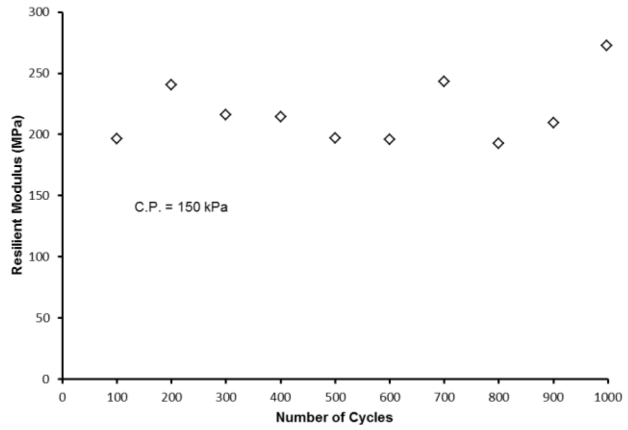

Figure 7 Resilient modulus versus no. of cycles (150 kPa)

3.3 Permanent deformation behaviour

Permanent deformations constitute the non-recoverable part of the deformations and are the mainly responsible for rutting in pavements. One of the key objective of pavement design is that the pavement is able to withstand permanent deformation beyond a certain, tolerable, level while permitting only resilient deformations. Since the deformation of the various layers of the pavement structure leads to irreversible deformations at the pavement surface, a pavement should be designed to such a degree that only small amount of permanent deformation can accumulate in each layer. Figure 8 shows axial permanent strain results at a confining pressure of 50 kPa in relation to the number of loading cycles.

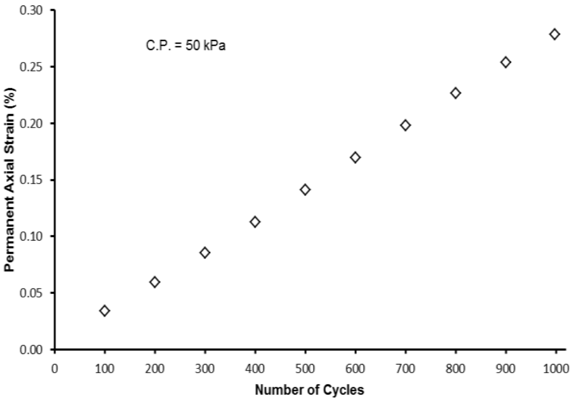

Figure 8 Axial permanent strain versus no. of cycles (50 kPa)

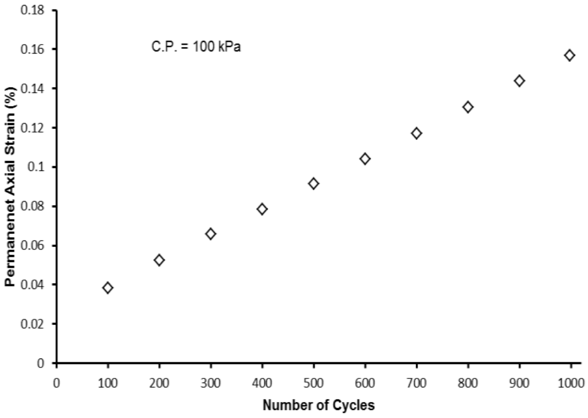

Figure 9 Axial permanent strain versus no. of cycles (100 kPa)

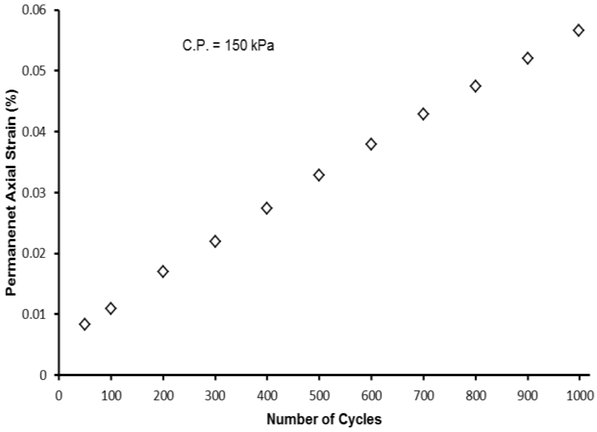

Figure 10 Axial permanent strain versus no. of cycles (150 kPa)

It is clearly seen that the permanent strain follows linear relationship with the number of load cycles. Generally, the permanent deformation rises immediately during the initial first cycles followed by gradual stabilization. But the amount of deformation depends on the material characteristics and applied load. Rounded particles such as fly ash slip over each other very easily and may cause significant permanent deformations. Additions of angular GGBS particles would be beneficial in the reduction of permanent deformation since angular shaped materials have to overcome higher frictional stresses.

It can be clearly seen that with increasing number of load cycles, the magnitude of accumulated permanent strains also increase although stabilization of the strain is not found. Similar linear relationships between permanent axial strain and number of cycles are found with the increase in the confining pressure (Figures 9 and 10). However, the accumulated permanent strain at the end of the load cycles is seen to reduce with the increase in confining pressure with lowest strain at 150 kPa. Table 2 presents the permanent deformations or strains of the sample at various confining pressures at the end of 1,000 cycles. The results clearly illustrate that the increase in the confining pressure reduces the permanent axial strain.

Table 2 Permanent percentage strains at different confining pressures

Confining pressure (kPa)	Plastic Strains, ε_p (%)
50	0.28
100	0.16
150	0.06

3.4 Modeling Permanent Deformation Behaviour

In mechanistic analysis, a number of models provide guidance in terms of resistance of a sub-base or base course layer to plastic damage. Various researchers have investigated the accumulation rate of permanent strain under repeated conditions and found that the rate of permanent strain decreases with the number of load reputations. Various model studies have been carried out by many researchers to predict the permanent strain behaviour from number of load applications. A comprehensive study using cyclic load triaxial test was carried out by Barksdale (1972) on the behaviour of different base course materials. He was the first to establish a well-known relationship between permanent strain (ε_p) and number of load applications (N) using a lognormal method as shown in the following equation.

$$\varepsilon_p = a + b \log N \tag{1}$$

Where a and b are experimentally derived parameters.

Later, Sweere (1990) modified the lognormal approach and suggested the following equation to relate permanent strain with number of cycles using a log-log relation.

$$\log \varepsilon_p = a + b \log N \tag{2}$$

A large number of models are available to describe the permanent strain behaviour. Because of its simplicity, only the model modified and proposed by Sweere (1990) is applied and validated in this study.

Figure 11 shows the log-log relationship between the permanent strain and number of cycles given by this model at a confining pressure of 50 kPa. It can be clearly noticed that the model fits very well with the experimental results.

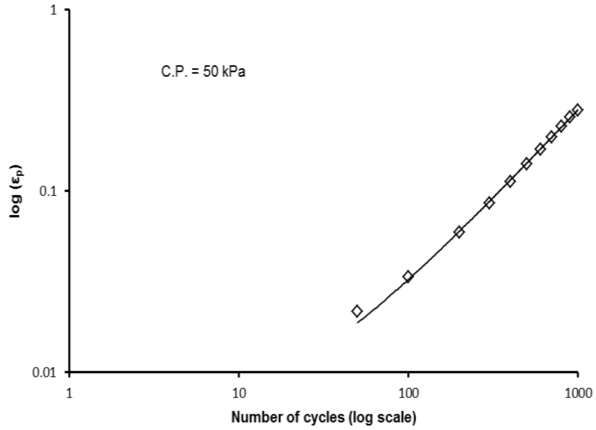

Figure 11 Comparison between the model and the experimental results (50 kPa)

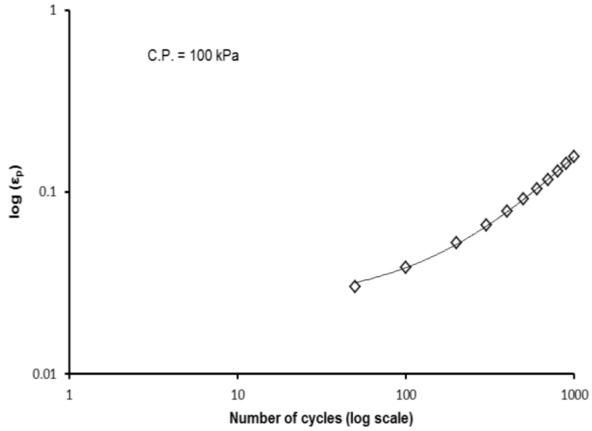

Figure 12 Comparison between the model and the experimental results (50 kPa)

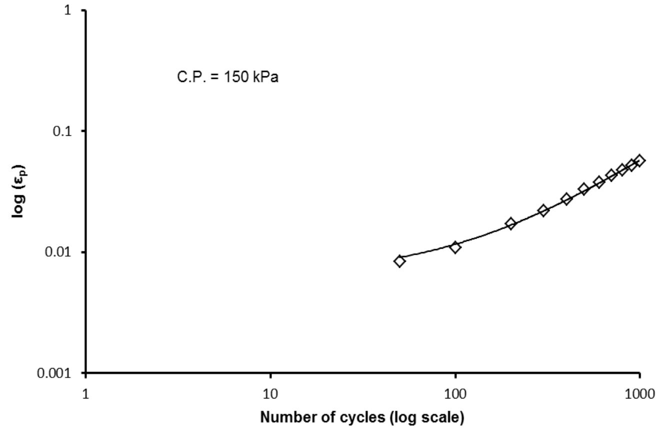

Figure 13 Comparison between the model and the experimental results (50 kPa)

Log-log relation between the permanent strain and number of cycles at higher confining pressures exhibits similar results and are shown in Figures 12 and 13.

4 CONCLUSIONS

Shape and size of fly ash and GGBS are the main factors controlling the compressibility, resilient and permanent deformation characteristics. The addition of GGBS to fly ash makes the mixture well graded and as a result compressibility is reduced. The higher resilient modulus values indicate that the mixture of fly ash and GGBS can be suitably utilised as sub-grade materials in construction of roads. Permanent axial strain increased with the load cycles. But the accumulation of plastic strain reduced with increase in confining pressure. The compressibility and permanent deformation behaviour test demonstrate that if properly designed, the mixture can be utilised economically for the construction of embankments, road sub-grades etc.

5 REFERENCES

Araya, A.A., 2011, Characterization of unbound granular materials for pavements. Delft University of Tech., Road and Railway Engineering Section, Fac. of Civil Engineering and Geosciences.

Barksdale, R.D., 1972. Laboratory evaluation of rutting in base course materials. In: Presented at the Third International Conference on the Structural Design of Asphalt Pavements, Grosvenor House, Park Lane, London, England, Sept. 11-15, 1972.

Dondi, M., Marsigli, M., Fabbri, B., 1997, Recycling of industrial and urban wastes in brick production: a review (Part 2). Tile & brick international 13, 302-315.

Gabr, A., Mills, K., Cameron, D., 2013, Repeated load triaxial testing of recycled concrete aggregate for pavement base construction. Geotechnical and Geological Engineering 31, 119-132.

Kaniraj, S.R., Gayathri, V., 2004, Permeability and consolidation characteristics of compacted fly ash. Journal of energy engineering 130, 18-43.

Mishra, D.P., Das, S.K., 2012, One-Dimensional Consolidation of Sedimented Stowed Pond Ash. Geotechnical and geological engineering 30, 685-695.

Pappu, A., Saxena, M., Asolekar, S.R., 2007, Solid wastes generation in India and their recycling potential in building materials. Building and Environment 42, 2311-2320.

Puertas, F., Martínez-Ramírez, S., Alonso, S., Vazquez, T., 2000, Alkali-activated fly ash/slag cements: strength behaviour and hydration products. Cement and Concrete Research 30, 1625-1632.

Rodriguez, J.M., 2013, Importance of the Particle Shape on Mechanical Properties of Soil Materials.

Singh, M., Garg, M., 1999, Cementitious binder from fly ash and other industrial wastes. Cement and Concrete Research 29, 309-314.

Sridharan, A., Sivapullaiah, P.V., 2005, Mini compaction test apparatus for fine grained soils. Geotechnical Testing Journal 28, 1-7.

Sweere, G.T., 1990. Unbound granular bases for roads. Technische Universitiet Delft,

Tu, W., Zand, B., Ajlouni, M.A., Butalia, T.S., Wolfe, W.E., 2007, The Consolidation Characteristics of Impounded Class F Fly Ash–A Case History. Proc. World of Coal Ash.