VOL. 11, NO. 13, JULY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

EFFECT OF COMPACTION DENSITY AND MOISTURE CONTENT LEVEL ON SHEAR STRENGTH BEHAVIOUR OF FLY ASH MIXED COAL MINE OVERBURDEN DUMP MATERIAL

Pankaj Kumar Dewangan[1], Manoj Pradhan[1] and G. D. Ramtekkar[2]
[1]Faculty, Department of Mining Engineering, National Institute of Technology, Raipur, C G, India
[2]Faculty, Department of Civil Engineering, National Institute of Technology, Raipur, C G, India
E-Mail: pankajnitrr@yahoo.co.in

ABSTRACT

Mixing and compaction of fly ash with the coal mine overburden dump material in presence of water result in complex shear strength behaviour of the mixture. Both fly ash and overburden dump material are cohesionless and non plastic material. But when they are mixed in presence of water and consolidate for some time, it hardens and changes the shear strength behaviour of the mixture. In this study, a series of small and large scale direct shear tests were conducted to assess the effect of mixing fly ash in two ratios i.e. 20 and 25% by volume on the shear strength behaviour of coal mine overburden dump material. With the addition of fly ash, the cohesion of the overburden dump material increased significantly while reduction in friction angle of the dump material was noticed. The reduction in friction angle got more pronounced with the increase in fly ash percentage. The effect of compaction density and moisture content levels on shear strength behaviour was also evaluated. Both cohesion and angle of internal friction was found to be decreased for the mixture compacted at lesser density. The overall mobilized shear strength was found slightly increased for the mixtures compacted at the moisture content below the optimum moisture content (OMC) due to increase in its friction angle component.

Keywords: overburden dumps, fly ash, cohesion, internal friction angle, direct shear test

1. INTRODUCTION

Indian power sector is undergoing a significant change that has redefined the industry outlook. Sustained economic growth continues to drive electricity demand in India. The Government of India's focus on attaining 'Power for All' has accelerated capacity addition in the country. In August 2015, the installed power generation capacity of India stood at 2, 76, 783 MW and current installed capacity of coal based thermal Power is 1, 68, 208 MW which comes to 60.8 % of total installed base. Coal based thermal power plants are primary source of power generation in India. Approximately 1, 00, 000 MW of new power generation capacity is expected to come up in the country within five years. Out of this, major portion of around 60 per cent would come from coal based thermal power plants. Indian coals are low in calorific value and high in ash content. Indian Thermal Power Plants (TPP) are facing problems of disposal of fly ash. Continuous research either for its effective utilization in various industries or safe disposal in mine voids and low lying areas are being carried out in India. In spite of lot of efforts and stringent regulation by the Ministry of Environment and Forest (MoEF), Govt. of India, the utilization of fly ash in India has achieved merely 60 %, most of which is being utilized for making cement, bricks and concrete and remaining being disposed off in ash ponds. A very little percentage (6 to 10 %) of fly ash generated is being disposed off in mines and reclamation of low lying areas in India (Central Electricity Authority, 2014). Location of TPP near open cast coal mines in India and huge availability of fly ash and overburden dump rock material there on can create very favourable conditions for disposing these waste materials in mine voids. Recent notification issued by MoEF dated 3rd November 2009 has made mandatory to utilize fly ash for reclamation and compaction of low lying areas and construction of roads and embankments for all the construction activities carried out within radius of 100 km from TPP. A similar compulsion has been made for stowing of underground mine voids with fly ash and mixing of 25% fly ash by volume in the overburden dumps formed in all the opencast mines situated within a radius of 50 km from TPP.

Fly ash is non-plastic, fine powdery material generally having negligible cohesion in dry condition and internal friction angle in the range of 29^0 to 37^0, (Pandian 2004), while under wet condition it hardens and strengthen with age due to its self-cementing properties and exhibits some cohesion (Porbaha *et al*. 2000). Fly ash consists of often hollow spheres of silicon, aluminium, and iron oxides and unoxidized carbon and is pozzolanic in nature and contains some lime. A lot of research has been carried out on stabilization of expansive soil with fly ash and it has been revealed that mixing of fly ash improves the performance of soil by improving its Atterberg limits, compressive strength, durability, hydration, permeability and compaction characteristics (Cokca, 2001; Prabhakar *et al.* 2004; Sharma *et al*. 2006; Geliga *et al*. 2010, Brooks *et al*. 2011; Bose, 2012; Takhelmayum *et al*., 2013). Addition of fly ash in the soil also resulted in increased shear strength of the mixture (Phani Kumar and Sharma, 2004).

Coal mine overburden dump materials mostly contain coarse grained particles to rock fragments grading to fine grained particles and consist of soil, fragments of sandstone, carbonaceous shale and some coal bands

ARPN Journal of Engineering and Applied Sciences

(Ulusay *et al*. 1995). The overburden dumps in most of the opencast coal mines are usually formed by end tip dumping method in which the dumpers backs right up the dump face and discharges material directly down face. The end tip dumping method results in formation of dumps with relatively low density. Compaction of the dump matrix occurs by the weight of added material and by dumper movement on it without the use of any specific compaction equipment and little attention is given towards its compaction requirement without any specific measurement of the maximum compaction density possible in that material. Compaction density is one of the most important parameter for any engineering fill design structures. Compaction improves the shear strength and other engineering properties of the fill (Sridharan, 2006; Ugbe, 2011; WangLong *et al*. 2011). If the overburden dumps are compacted near its maximum dry density, it will not only accommodate more volume of overburden material in the same area of land but it will also allow steepening of the dump slope angle to some degree because of shear strength enhancement resulting due to better compaction.

There are two main safety and environmental concerns in the disposal of fly ash when it is mixed with the overburden dumps, the first one is related with changes in shear strength behaviour of the overburden dumps and its stability and second one related with the ground water contamination from fly ash leachates. Some research has been carried out on the environmental characteristics of Indian fly ash leachates and it has been reported that the fly ash interaction with the ground/mine water produces toxic elements well below the permissible/threshold levels (Singh, 2005; Maiti *et al*. 2005; Sarode *et al*. 2010; Kumar Ritesh, 2010; Behra and Mishra, 2012). Ground water contamination due to leaching of heavy and toxic metals from fly ash can also be minimized and controlled if they are separated from the ground water aquifer by suitable liners (Snigdha and Batra, 2006). A plenty of research regarding effect of mixing fly ash with mine overburden rock on its CBR were conducted to investigate the suitability of fly ash as a road construction material (Pandian, 2004; Kim *et al*. 2005; Arora and Aydilek, 2006; Edil and Benson, 2007; Okunade, 2010; Kumar, 2010; Santos *et al*. 2011). Utilization of fly ash for construction of highway embankments has also been investigated by some researchers (Martin *et al,* 1990; Yoon *et al*. 2009).

Very few research work were found available which has examined the change in shear strength behaviour of mixing fly ash with coal mine overburden dump materials and the stability of fly ash mixed overburden dumps. Singh, 2011, studied the effect of mixing 30% fly ash on factor of safety for an overburden dump slope of a height of 120 m under both under dry and wet conditions using numerical simulation. He found that the slope remained stable under dry condition while under wet condition reduction in factor of safety of the slope was reported. Jayanthu *et al*, 2012, studied the dump stability of fly ash (25 % by weight) mixed overburden dumps of an opencast coal mine having a total height of 120 m. Two types of dumps were formed, one with alternate layer of fly ash and overburden and the other by mixing fly ash in the overburden dumps. In both conditions, dumps were found stable. Pradhan *et al*. 2014 also analyzed the stability of dump slope of 60 m height having an overall slope angle of 32^0 made up of overburden materials randomly mixed with 20% fly ash and found the slope stable. In all the above studies, shear strength parameters for slope stability analysis were determined by conducting small scale triaxial tests on fly ash mixed with sand and silty fractions of dump material. The main drawback of the studies was the inclusion of only fine portion of the dump material for shear strength determination of the mixture formed with fly ash. A shortcoming to this small scale laboratory testing is that oversized rock fragments are usually scalped to accommodate the testing equipment capacity. The influence of coarser fraction of rock fragments present on the overburden dumps on shear strength is not taken in to consideration. Also the confining stress ranges during the test was low which may sometimes cause overestimation of shear strength parameters. These can lead to uncertainties associated with the assignment of accurate shear strength parameters for slope stability modelling and design. Determination of accurate shear strength characteristics of fly ash mixed mine overburden rock is one of the most important parameter in design and analysis of stability of fly ash mixed overburden dump slopes. Therefore this research work aims to investigate the shear strength behaviour of fly ash mixed overburden dump rocks of coal mines by conducting a series of small and large scale direct shear tests at various compaction densities and moisture content levels. The rate of confining stress chosen is suitable for design of slopes up to 60 m high. This study also aims to characterize the shear strength behaviour of fly ash mixed overburden dump rocks of coal mines by conducting a series of small and large scale direct shear tests which takes care of both fine and coarse sized rock fragments present in the dump materials.

2. MATERIALS AND METHODS

Bulk quantities of overburden dump samples were collected from a large, partially consolidated rock dump from a large open-cast coal mine situated in Korba area of SECL and samples of fly ash were collected from one of the thermal power plant located in Siltara, Raipur (C.G.). During collection of samples from the dump, rock fragments more than 80 mm in size were discarded at the site itself. Particle size analysis of the dump materials were carried out in the laboratory as per IS Standard IS: 2720 (part 4) 1985 to know the size distribution of the rock fragments forming the dump and a modelled gradation curve (proto type sample) was prepared to represent the size of rock fragments present in the dump material.

Testing the proto type dump material was not possible with the available size of the shear boxes. Therefore, the laboratory specimens were scaled by some degrees and all the compaction and shear tests were performed on this reduced gradation which is parallel to

VOL. 11, NO. 13, JULY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

the proto type. During sieving of dump sample, the rock fragments passing through different sieve sizes ranging from 31.5 mm to less than 200 µm were collected in separate bags. Using parallel gradation technique developed by John Lowe,1964, the rock fragments of various size collected in different bags were then mixed together to produce a well graded experimental sample having size distribution parallel to the proto type representing the particle size distribution of the actual dump material in the field. Numerous researchers have tested materials based on this model and validated the effectiveness of this model to estimate the shear strength of rock fills and rail ballast(Sitharam and Nimbkar, 2000; Cambio and Gay, 2007; Ganbhari, 2008; Sevi, 2008). In this research, test gradation was made following the above method using two maximum particle diameters of 31.5 mm and 4.75 mm considering the size of the large and small shear box (300 mm x 300 mm x 190 mm and 60 mm x 60 mm x 31 mm, respectively). After oven drying of rock fragments separated through sieving, two different types of modelled material were prepared to represent coarse and fine grained dump rock material and were named as GTODS1 and STODS. The gradational characteristics of the including fragment size, gravels and fines content, uniformity coefficient, coefficient of curvature etc. are summarized in Table-2. The gradation curve of both GTODS1 and STODS were kept parallel to proto type sample (PTS) keeping their uniformity coefficient and coefficient of curvature same having the same gradational characteristics as that of PTS (Figure-1). These prepared samples were having average fragment size of 9 and 1.6 mm. The objective of preparing two different mixtures was to quantify the effect of fragment size on the shear strength behaviour of the fly ash mixed overburden dump samples.

The various relevant geotechnical index properties were measured in the laboratory to classify the investigated materials. Laboratory tests were carried out on the experimental overburden dump material, which include moisture content, specific gravity, point load strength index, slake durability index tests, Atterberg limits etc. The specific gravity of the experimental samples containing overburden rock fragments were determined using volumetric flask method as per IS: 2720 (Part 3-1980). Point load strength index and slake durability of the dump rock material were determined as per IS: 8764 (1998) and IS: 10050 (1981) test procedure respectively.

Heavy Procter compaction tests were conducted as per IS: 2720 (Part 8 -1983) to establish the maximum dry density and optimum moisture content of the coarse grained rock dump sample i.e. GTODS1. To measure the maximum dry density and optimum moisture content of fine grained dump material i.e. STODS and fly ash, light compaction tests were conducted for each material separately as per IS: 2720 (Part 7-1980).

Table-1. Gradational characteristics of experimental overburden dump material.

Gradation characteristics	**Insitu dump sample**	**Coarse fractions of overburden dump material**	**Fine fractions of overburden dump material**
Maximum fragment size, D_{max}, mm	80	31.5	4.75
Average fragment size, D_{50}, mm	18.5	9.00	1.60
Coefficient of uniformity, C_u	23	24	23
Coefficient of curvature, C_c	2.80	2.78	2.78
Gravel content, > 4.75 mm	78	67	0
Silt and clay content, < 0.075 mm by weight	5	5	8
Group symbol as per BIS	GW	GW-GM	SM
Sample name	Proto Type Sample (PTS)	Gravel Type Overburden Dump Sample 1 (GTODS1)	Sand Type Overburden Dump Sample (STODS)

VOL. 11, NO. 13, JULY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

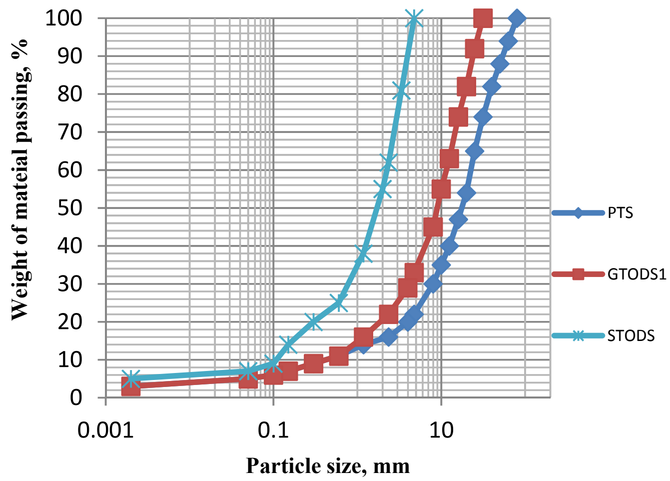

Figure-1. Gradation curves of experimental overburden rock materials and Proto type.

Table-2. Geotechnical properties of Overburden dump rock material.

Properties	Overburden dump material	Fly ash
Specific gravity	2.65	2.10
Liquid limit	18.60%	35%
Plastic limit	Non plastic	Non plastic
Point load strength index, MPa	0.4 to 1	NA
Maximum unit weight, kN/m^3	19.83	13.34
Optimum moisture content, %	9.00	25.00

It is practically difficult to form a homogeneous mixture of fly ash mixed overburden dumps containing 25 % fly ash by volume at the site, therefore two types of mixture containing approximately 20 % and 25 % of fly ash by volume in the overburden dump sample were prepared to investigate the influence of increasing fly ash percentage on the shear strength behaviour of overburden dumps (Table-3). Oven dried weights of the both test materials were used to decide the ratio of fly ash proportions and knowing there density, corresponding volumes were calculated. Procter compaction tests were conducted to establish moisture content - dry unit weight relationship of each of these composite mixtures Figure-3.

Table-3. List of experimental samples prepared for various compaction and shear tests.

Name of the sample	Composition	**Compaction tests** (Heavy /Light)	**Direct shear tests** (Large/ Small)
GTODS1	Coarse fractions of overburden (OB) dump material	Heavy	Large
STODS	Fine fractions of OB dump material	Light	Small
GTODS1M20F	80% OB + 20% FA	Heavy	Large
GTODS1M25F	75% OB + 25% FA	Heavy	Large
STODSM20F	80% OB + 20% FA	Light	Small
STODSM25F	75% OB + 25% FA	Light	Small

Large scale direct (LSD) shear tests for this study were carried out using multispeed direct shear equipment. In the direct shear test, the soil was compacted in five different layers and then consolidated for some time under an applied normal stress. After consolidation, the specimen was sheared directly at a constant rate of

VOL. 11, NO. 13, JULY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

deformation. To avoid the build of pore water pressure during the test, the strain rates chosen were very low and of the order of 0.2 mm/min. Small scale direct (SSD) shear tests were carried in a similar manner at the same strain rate.

In order to study the effect of moisture content, samples were compacted at two different moisture content levels, first one corresponding to optimum moisture content and second one prepared at natural moisture content of 4%. In each layer compaction was conducted using a 2.5 kg rammer so as to obtain 90% compaction relative to so that the results are comparable.

In the similar way, direct shear tests were also carried out on the samples compacted at 80% of the maximum dry density and at OMC to assess the influence of compaction density on shear strength behaviour of these composite mixtures.

All the LSD shear tests were conducted as per IS 2720 (Part 39, Sect. 1-1977) at five different values of normal stress levels (73.57 kPa to 469.79 kPa) and corresponding shear loads, vertical and horizontal (shear) displacements were monitored and recorded.. SSD shear tests were conducted on fine grained overburden dump sample and their mixtures with fly ash at normal stress ranging from 34.33 kPa to 245.35 kPa. This corresponds to average normal stresses built up in embankment fills/slope heights of 10 m to 60 m.

3. RESULTS AND DISCUSSIONS

3.1 Effect of fly ash mixing on compaction behaviour

Figure-2 depicted the compaction curves of prepared experimental overburden dump material along with the zero-air-void line and Figure-3 presents maximum dry unit weight versus optimum moisture content relationships obtained for fly ash and overburden dump sample mixed with fly ash in two ratios of 20 and 25% by volume. The shape of the compaction curve for fly ash is relatively flat as compared to overburden dump material. The variation of unit weight with moisture content for fly ash was found less compared to that for overburden dump material. Moulton (1978) as well as Sridharan et al. (2000) observed the variation of dry density with moisture content for fly ash to be less compared to that for a well-graded soil, both having the same median grain size. The tendency for fly ash to be less sensitive to variation in moisture content than for dump material could be explained by the higher air void content of fly ash. The higher void content in fly ash could tend to limit the build up of pore pressures during compaction, thus allowing the fly ash to be compacted over a larger range of water content (Toth *et al*. 1988; Sridharan *et al*. 2001). Sridharan *et al*. 2001 and Pandian and Mir, 2002 reported that the compaction curves of fly ash resemble those of cohesionless soils and the change in water content does not have significant effect on the dry unit weight.

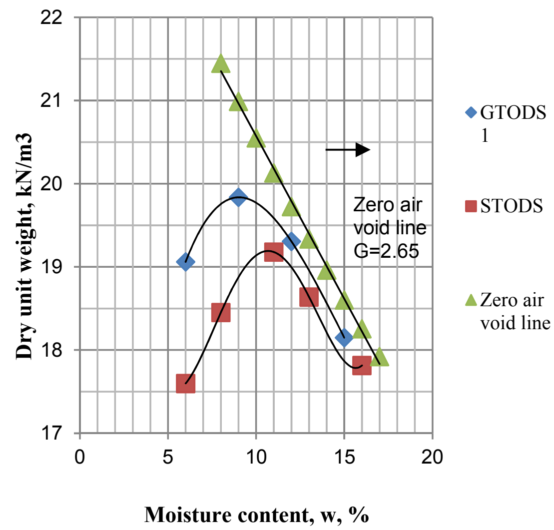

Figure-2. Dry unit weight vs. optimum moisture content of experimental overburden dump material GTODS1 and STODS with zero air void line (G=2.65).

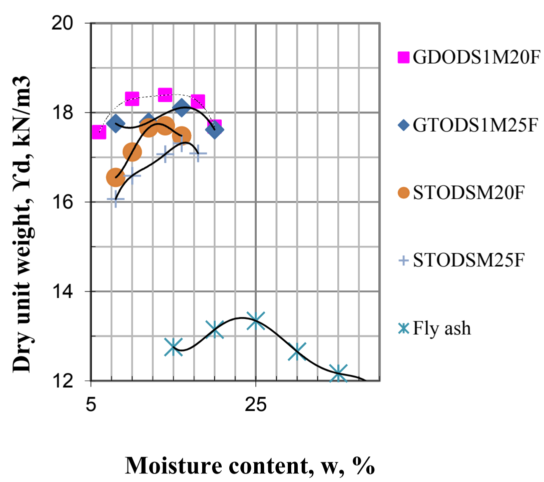

Figure-3. Dry unit weight vs. optimum moisture content of fly ash sample and experimental overburden dump material mixed with 20 and 25 % fly ash.

The addition and increase in fly ash amount resulted in decrease in its maximum dry unit weight and increase in optimum moisture content of the mixture. A reduction of 10-12 % in unit weight of the overburden dump material was observed with the addition of fly ash in the ratio of 20 to 25 % by volume.The results are consistent with past findings (Sridharan *et al.* 2001). The explanation for the trend is similar to that explained by past researchers. The decrease of the maximum dry unit weight with the addition of fly ash is firstly due to the lower specific gravity of the fly ash compared with dump material, and the immediate formation of cemented

VOL. 11, NO. 13, JULY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

products which reduce the density of the treated mixture (Lees et al. 1982, Bell 1996). Secondly because of cation exchange reaction, the flocculated and agglomerated soil/rock particles occupy larger spaces, thus increasing the volume of voids and consequently reducing the maximum dry density of the mixture. One of the reasons for the increasing OMC with the addition of fly ash may be attributable to the affinity of the mixture for more water for the completion of cation exchange reaction. Other reasons are due to poor gradation of fly ash and presence of broken hollow spheres in fly ash (Mir and shridharan 2013).

3.2 Effect of fly ash mixing on shear strength behaviour

In this study, a series of LSD and SSD shear tests were conducted to evaluate the effect of mixing fly ash in two ratios i.e. 20% and 25% by volume on the shear strength behaviour of fly ash mixed coarse grained and fine grained coal mine overburden dump material (named as GTODS1M20F, GTODS1M25F and STODSM20F, STODSM25F - refer Table 3). The results were compared with direct shear tests conducted on overburden dump material without fly ash. Both peak strength and residual strength values were identified from the results (Figures 4 and 5). The differences in the shear strength were quantified by determining the intercept with the shear stress axis giving apparent cohesion (peak and residual) and the slopes of the trend lines, estimating the friction angles (peak and residual). The Mohr-Coulomb failure envelope was approximated as linear within the stress range used in these tests. The measured cohesion in overburden dump material is due to moisture present in the samples that caused induced suction and also because of presence of some clay and silt fractions. However the apparent cohesion for overburden dump material was found very less and it is generally neglected by geotechnical engineers for slope stability design. Presence of this apparent cohesion in coal mine spoil material has been reported by Ulusay *et al.* 1995 and also in soil quarry dust mixtures by Sridharan *et al*. 2006. The value compares favourably with those obtained for coal mine spoil material elsewhere (Fernando and Nag 2003, Simmons 2004, Koner and Chakravarty, 2010; Kainthola *et al*. 2011; Rai *et al*. 2012; Verma *et al.* 2013).

With the addition of fly ash, the cohesion of the mixture increased significantly. Addition of fly ash resulted in greater degree of void filling between the rock particles as the voids get occupied by fly ash very easily. Also mixture gets somewhat hardened due to fly ash reaction with water and resulted in an increase in cohesion. However the friction angle got reduced with the mixing of fly ash. The results favours comparably with those reported elsewhere (Jayanthu, 2012 and Krisna and Nayak, 2015). The reduction in both peak and residual friction angle got more pronounced with the increase in fly ash percentage. The addition of fly ash in cohesionless dump material reduces particle to particle contact as it get trapped between the rock particles which can be considered as main reason for drop in friction angle of the mixture.

Table-4. Mobilized peak and residual shear stress for GTODS1, GTODS1M20F, GTODS1M25F, STODS, STODSM20F and STODSM25F.

Sample	Normal stress, kPa	Peak shear stress, kPa
GTODS1	73.57	69.18
	172.00	109.6
	269.775	150.03
	367.76	235.44
	465.79	279.77
GTODS1M20F	73.57	112.90
	172.00	140.95
	269.775	183.34
	367.76	226.39
	465.79	261.61
GTODS1M25F	73.57	105.54
	172.00	135.68
	269.775	178.06
	367.76	196.0
	465.79	232.2
STODS	34.33	36.78
	88.29	67.85
	172.00	106.82
	220.72	126.033
	245.35	140.05
STODSM20F	34.33	66.76
	88.29	81.205
	172.00	112.27
	220.72	132.70
	245.35	141.70
STODSM25F	34.33	74.12
	88.29	86.11
	172.00	116.63
	220.72	134.07
	245.35	149.33

VOL. 11, NO. 13, JULY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

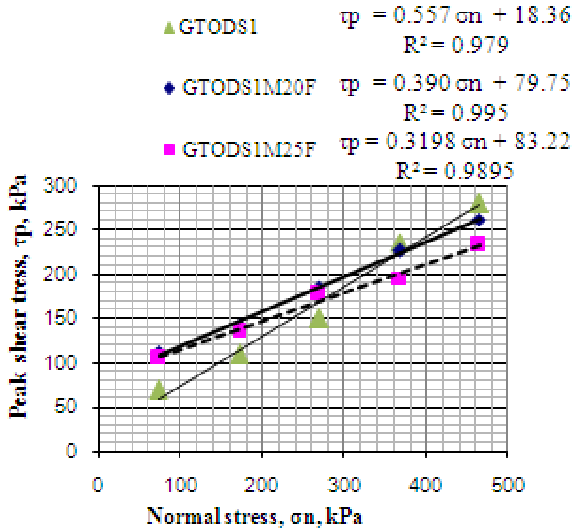

Figure-4. Mohr coulomb friction envelope for GTODS1, GTODS1M20F and GTODS1M25F.

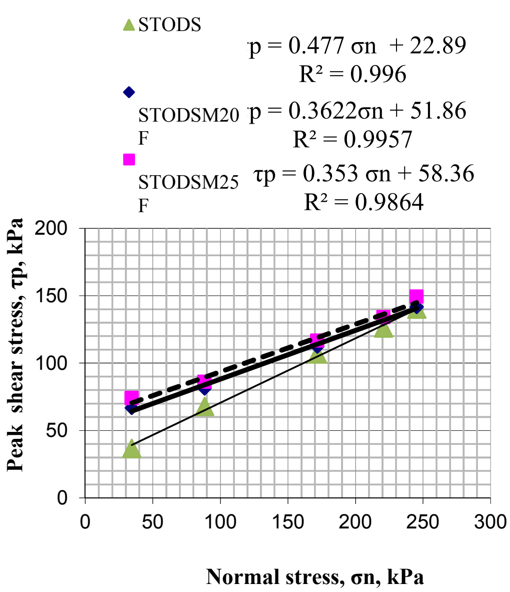

Figure-5. Mohr coulomb friction envelope for STODS, STODS1M20F and STODS1M25F.

The reduction in both peak and residual friction angle got more pronounced with the increase in fly ash percentage. The overall mobilized peak and residual shear stress for the fly ash mixed overburden dump material was found to be increased at low normal stress levels of up to 269.775 kPa, but as the normal stress increased further beyond this level, both peak and residual shear stress reduced slightly as compared to the mixture containing no fly ash (Table-4). With the addition of fly ash, the percentage of coarse fractions decreased which resulted in reduced dilational behaviour than overburden dump material at higher normal stress levels.

3.3 Effect of moisture content on shear strength behaviour

Direct shear tests were carried out on GTODS1 and GTODS1M20F at moisture content well below the OMC to investigate the effect of moisture on the shear strength behaviour. The natural moisture content (NMC) of GTODS1 was found 4% which is approximately 50% of OMC. Therefore it was decided to keep moisture content for GTODS1M20F at 8 % (Approx. 50% of OMC). The tests were carried at the same strain rate and normal stress levels. The friction angle was found to be increased by 2.85^0 and 1.85^0 for GTODS1 and GTODS1M20F respectively. However a very small reduction in cohesion was noticed for GTODS1, while a slight increase in cohesion was found for GTODS1M20F with the decrease in moisture content (Figures 6 and 8). The overall mobilized shear strength slightly increased for both of the mixtures compacted at the moisture content below the OMC due to increase in its friction angle component (Figures 7 and 9). These results confirm to similar observation reported elsewhere (Kandolkar *et al.* 2013 and Cokca *et al.* 2004). Kandolkar *et al.* 2013 conducted direct shear tests on stone dust compacted at OMC and below OMC and reported increased value of cohesion at OMC. An increase in cohesion was observed by Cokca *et al.* 2004 for clay as the compaction water contents approach the optimum value. One of the main reasons for this increase in apparent cohesion was due to increase in matric suction for sample compacted at lesser moisture content. Capillary stresses develop between particles in a partially saturated soil due to surface tension in the water. The surface tension (negative pressure) in the water produces an equal and opposite effective stress between the soil particles, which results in an apparent cohesion. The magnitude of this type of apparent cohesion can be extremely large, especially in fine grained soils. With the addition of fly ash, the percentage of fines increases significantly. The result clearly indicated that moisture has an important influence on the shear strength behaviour of fly ash mixed overburden dump material.

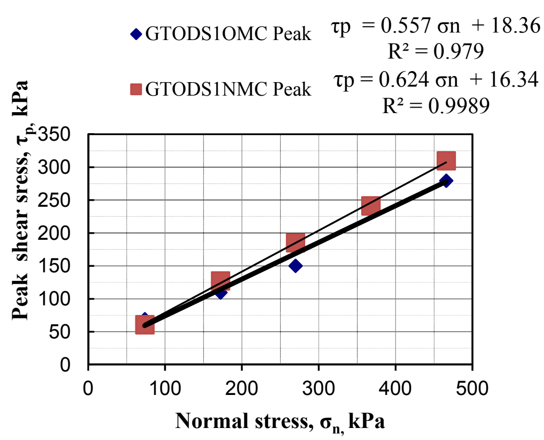

Figure-6. Mohr coulomb friction envelope for GTODS1 at OMC and NMC.

ARPN Journal of Engineering and Applied Sciences

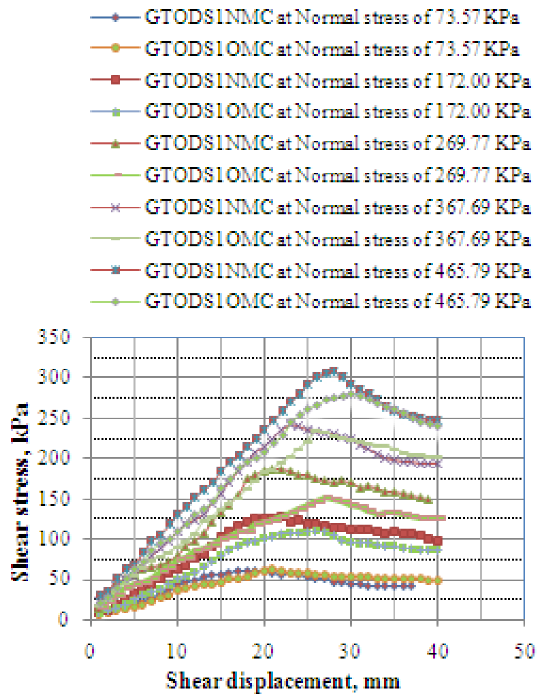

Figure-7. Shear stress vs shear displacement plot for GTODS1 compacted at OMC and NMC.

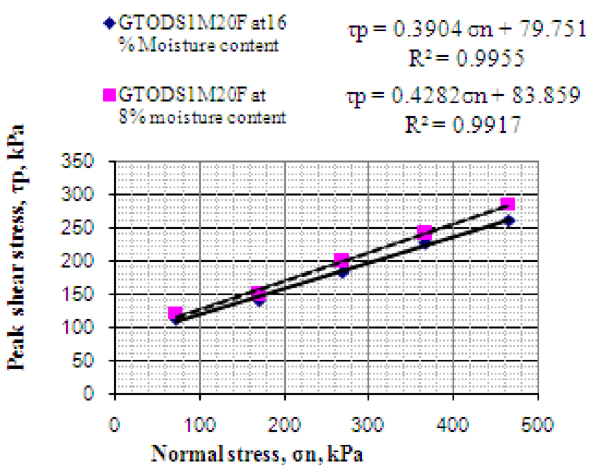

Figure-8. Mohr coulomb friction envelope for GTODS1M20F at OMC and NMC.

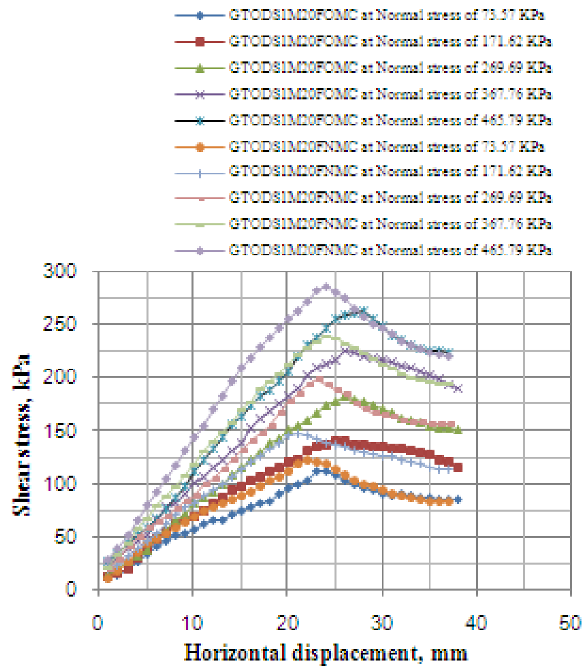

Figure-9. Shear stress vs shear displacement plot for GTODS1M20F compacted at OMC and NMC.

3.4 Effect of compaction density on shear strength behaviour

The effect of compaction density on the shear strength of fly ash mixed overburden dump material was studied by conducting large scale direct shear test on GTOS1M20F, which are compacted at two different unit weights of 16.68 kN/m^3 and 14.80 kN/m^3 (90 and 80% of maximum unit weight as determined from compaction tests). Both the samples were compacted at OMC. Both cohesion and angle of internal friction was found to be decreased for the mixture compacted at lesser density (Figure-10). The peak apparent cohesion was reduced from 79.75 kPa to 52.71 kPa and friction angle decreased from 21.33^0 to 18.77^0. In case of sample compacted at higher compaction density, the resisting shear stress increased with shear displacement until it reached the peak shear strength. The plot showed a marked curvature attaining peak shear stress. After failure stress was attained, the resisting shear stress gradually decreased as shear displacement increased until it finally reached a constant value called the ultimate shear strength (Figure-11). Dense material requires more dilation to fail as particles have less room to move during shearing which cause a distinct drop in the friction angle after failure. Greater density of packing resulted in higher cohesion among the particles.

While in case of sample compacted at lesser density, the shear resistance increased at very low rate for any further increase in the shear displacement once peak strength was attained. The curve did now show any distinct peak point in any of the tests. Here the peak strength was measured at around 25 mm of shear displacement (at 8.66 % shear strain as obtained in most of the other shear tests conducted in the same material. In lesser dense sample, the volume of the sample gradually decreased to a certain value and there is enough space for rock fragments to move during shear and reorientation of the fragments during shear took place.

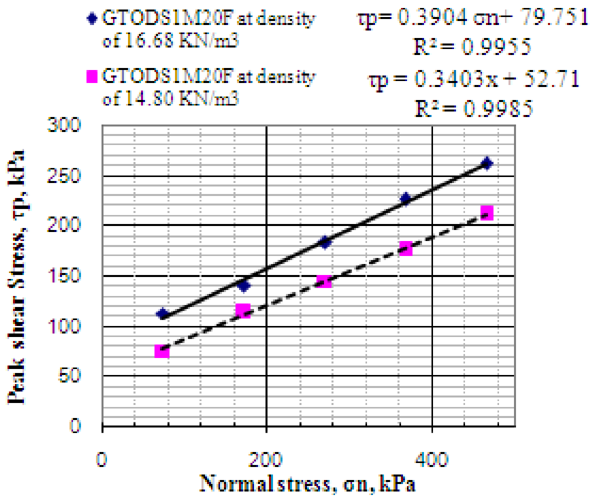

Figure-10. Mohr Coulomb shear strength envelope for GTODS1M20F compacted at 90 and 80 % of maximum compaction densities.

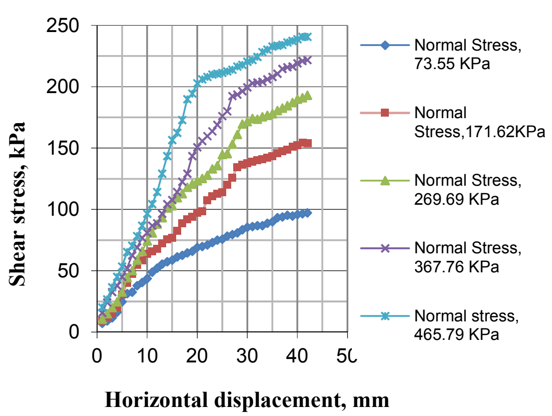

Figure-11. Shear stress vs shear displacement plot for GTODS1M20F compacted at 80 % of maximum compaction density.

4. CONCLUSIONS

In order to understand the shear strength behaviour of fly ash mixed coal mine overburden dump rock material, a series of large and small box direct shear tests were carried out on the coarse grained and fine grained fractions of dump material with two different fly ash proportions (i.e. 20 and 25% by volume) at varying compaction density and moisture content levels. Following conclusions were drawn on the basis of above study:

- A reduction of 10-12 % in unit weight of the overburden dump material was observed with the addition of fly ash in the ratio of 20 to 25 % by volume.
- With the addition of fly ash, the cohesion of the overburden dump material increased significantly. A slight reduction in friction angle of the dump material was noticed with the addition of fly ash. The reduction in friction angle got more pronounced with the increase in fly ash percentage.
- An increase in the overall mobilized peak and residual shear stress for the fly ash mixed overburden dump material was noticed at low normal stress levels up to 269.775 kPa, but as the normal stress increased further beyond this level, both peak and residual shear stress reduced slightly as compared to the mixture containing no fly ash.
- The overall mobilized shear strength was found slightly more for mixture compacted at the moisture content below the OMC due to significant increase in its friction angle component. However a small reduction in cohesion was noticed with the decrease in moisture content.
- In case of sample compacted at higher compaction density, the resisting shear stress increased with shear displacement until it reached the peak shear strength. While in case of sample compacted at lesser density, the shear resistance increased at very low rate for any further increase in the shear displacement once peak strength was attained. Both cohesion and angle of internal friction was found decreased for the mixture compacted at lesser density.

This study emphasises the importance of compaction density and moisture content on shear strength behaviour of fly ash mixed coal mine overburden dump material. The findings of this study will be useful to select appropriate value of moisture content and compaction density at which fly ash mixed overburden dumps can be formed in the coal mines while keeping a check on its shear strength parameters and hence the stability of the dumps so formed.

ACKNOWLEDGEMENTS

The authors are thankful to the management of South Eastern Coal Fields Limited, Bilaspur and Siltara Thermal Power Plant, Raipur for providing samples of overburden dump m and fly ash respectively. The authors are also thankful to Head of the Department and Director of National Institute of Technology, Raipur for giving permission to publish this paper. This work is a part of doctoral thesis of first author. The views expressed in this paper are solely of the authors and any of the above organizations will not be held responsible.

REFERENCES

Arora Sunil, and. Aydilek Ahmet H, 2006. Class F Fly-Ash- Amended Soils as Highway Base Materials. Journal of Materials in Civil Engineering. 17(6): 640-649.

Behera B. and Mishra M. K. 2012. Microstructure and Leaching Characteristics of Fly Ash-Mine Overburden-Lime Mixtures, Proceedings of International Conference on Chemical, Civil and Environmental Engg., (ICCEE-2012), Dubai. pp. 256-260.

Bose Bidula. 2012. Geo-Engineering Properties of Expansive Soil Stabilized with Fly Ash, Electronic Journal of Geotechnical Engg. Vol. 17, Bundle J. pp. 1339-1354.

Brooks Robert, Udoeyo Felix F. and Takkalapell Keerthi V. 2011. Geotechnical Properties of Problem Soils Stabilized with Fly Ash and Limestone Dust in Philadelphia. Journals of Materials in Civil Engg. 23(5): 711-716.

Cambio Domenica and Ge Louis. 2007. Effect of parallel gradation on strength properties of ballast Material, Proceedings of Advances in Measurement and Modeling of Soil Behavior, Denver, Colarado. pp. 1-7.

Cocka Erdal. 2001. Use of Class C Fly Ashes for the Stabilization of an Expansive Soil. Journal of Geotechnical and Geoenvironmental Engineering. 127(7): 568-573.

Edil Tuncer B. and Benson Craig H. 2007. Sustainable Construction Case History: Fly Ash Stabilization of Road Surface Gravel. World of Coal Ash, Northern Kentucky, USA, pp. 1-12.

Geliga Emilliani Anak and Ismail Dygku Salma Awg, 2010. Geotechnical Properties of Fly Ash and its Application on Soft Soil Stabilization, UNIMAS, E-Journal of Civil Engg. 1(2): 1-6.

Ghanbari Ali, Sadeghpour Amir Hossien and Mohamadzadeh Masoud, 2008. An Experimental Study on the Behaviour of Rockfill Materials using Large Scale Tests, Electronic Journal of Geotechnical Engg. Vol 13, Bundle G, pp. 1-16.

IS: 2720 -Part 4. 1985. Indian Standard Methods of Test for Soils: Grain size analysis, Bureau of Indian Standards

IS: 2720 -Part 39, Section 1. 1979. Indian Standard Methods of Test for Soils: Direct Shear Test For soil containing gravel more than 4.75 mm size, Bureau of Indian Standards.

IS: 10050. 1981. Indian Standard methods: Method for Determination of Slake Durability Index of Rock, Bureau of Indian Standards, New Delhi, India. pp. 1-7.

IS: 2720- Part 7. 1980. Indian Standard Methods of test for soils: Determination of Water Content-Dry Density Relation Using Light Compaction. Bureau of Indian Standards, New Delhi, India. pp. 1-8.

IS: 2720 -Part-5. 1985. Indian Standard Methods of Test for Soils: Determination of Liquid and Plastic Limit, Bureau of Indian Standards, New Delhi, India.

IS: 2720-Part 16. 1987. Indian Standard methods of test for soils: Laboratory Determination of CBR, Bureau of Indian Standards, New Delhi, India. pp. 1-15.

IS: 2720-Part 3. 1980. Indian Standard Methods of test for soils: Determination of Specific gravity. Bureau of Indian Standards, New Delhi, India. pp. 1-8.

IS: 2720-Part 8. 1983. Indian Standard methods of test for soils: Laboratory Determination of Water Content-Dry Density Relation Using Heavy Compaction, Bureau of Indian Standards, New Delhi, India. pp. 1-9.

IS: 8764, 1998. Indian Standard: Method for Determination of Point Load Strength Index of Rocks, Bureau of Indian Standards, New Delhi. pp. 1-10.

Jayanthu S., Das Sarat K. and Sk. Md. Equeenuddin, 2012. Stability of Fly Ash and Overburden Material in Opencast Mines- A Case Study. Proceedings of International Conference on Chemical Civil and Environmental Engineering, pp. 276-278.

Kim Bumjoo, Prezzi Monica and Salgado Rodrigo. 2005. Geotechnical Properties of Fly and Bottom Ash Mixtures for Use in Highway Embankments. Journal of Geotechnical and Geoenvironmental Engineering. 131(7): 914-924.

Kumar M. Anjan, Prasad D. S.V. and Prasada Raju G. V. R. 2010. Performance Evaluation of Stabilized Fly Ash Subbases. ARPN Journal of Engineering and Applied Sciences. 5(8): 50-57.

Kumar Ritesh 2010. Comparative Study of Leachate Characteristics of Pond Ash from Long-Term Leaching and Ash Pond Disposal Point Effluent from Chandrapura Thermal Power Station, India, E-Journal of Chemistry (http://www.e-journals.net), 7(S1), S131-S136, pp. 1-6.

Lowe John, 1964. Shear Strength of Coarse Embankment Dam Materials, Proceedings of 8th Congress on Large dams. pp. 745-761.

Maiti S.K., Singh Gurdeep, Srivastava S.B. 2005. Study of the Possibility of Utilizing Fly Ash for Backfilling and Reclamation of Opencast Mines: Pilot and Field Scale

Study with Chandrapura Fly Ash, Fly Ash Utilization Programme (FAUP), TIFAC, DST, New Delhi. pp. XII 31.1-31.13.

Martin Joseph P., Collins Robert A., Browning John S. and Bieh Francis J. 1990. Properties and Use of Fly Ashes for Embankments. Journal of Energy Engineering. 116(2): 71-86.

Ministry of Environment and Forest Notification, 3rd Nov. 2009. The Gazette of India: Extraordinary Part II, Section 3 (ii), New Delhi, Govt. of India.

Ministry of Power, Central Electricity Authority (CEA), August 2014. Annual Report. pp. 01-12.

Okunade Emmanuel Akintunde. 2010. Geotechnical Properties of Some Coal Fly Ash Stabilized Southwestern Nigeria Lateritic Soils. Modern Applied Science. 4(12): 66-73.

Pandian NS. 2004. Fly ash characterization with reference to geotechnical applications. J Indian Inst Sci. 84: 189-216.

Phani Kumar B.R. and Sharma Radhey S. 2004. Effect of Fly Ash on Engineering Properties of Expansive Soils, Journal of Geotechnical and Geoenvironmental Engineering. 30(7): 764-767.

Porbaha A., Pradhan T.B.S, and Yamane N. 2000. Time Effect on Shear Strength and Permeability of Fly Ash, Journal of Energy Engineering. 15: 15-31.

Pradhan S.P., Vishal V, Singh T.N., Singh V.K. 2014. Optimisation of dump slope geometry vis-a-vis fly ash Utilization using numerical simulation. American Journal of Mining and Metallurgy. 2(1): 1-7.

Prabakar J., Dendorkar Nitin and Morchhale R.K., 2004. Influence of Fly Ash on Strength Behavior of Typical Soils. Construction and Building Materials. 18: 263-267.

Santos Fabio, Li Lin, Li Yadong and Amini Farshad, 2011. Geotechnical Properties of Fly Ash and Soil Mixtures for Use in Highway Embankments. Proceedings of World of Coal Ash Conference. pp. 1-11.

Sarode Dhananjay Bhaskar, Jadhav Ramanand Niwratti, Vasimshaikh Ayubshaikh Khatik, Ingle Sopan Tukaram, Attarde Sanjay Baliram, 2010. Extraction and Leaching of Heavy Metals from Thermal Power Plant Fly Ash and its Admixtures. Polish J. of Environ. Stud. 19(6): 1325-1330.

Sevi Adam F. 2008. Physical Modelling of Rail Road Ballast Using the Parallel Gradation Scaling Technique within the Cyclical Triaxial Framework. PhD Thesis, Missouri University of Science and Technology. pp. 7-13.

Sharma Neeraj Kumar, Swain S.K., Sahoo Umesh C. 2006. Stabilization of a Clayey Soil with Fly Ash and Lime: A Micro Level Investigation. Journal of Geotechnical and Geological Engineering. 24(2): 1-11.

Singh Gurdeep. 2005. Environmental Assessment of Fly Ash from Some Thermal Power Stations for Reclamation of Mined Out Areas. Fly Ash Utilization Programme (FAUP), TIFAC, DST, New Delhi. pp. IV 9.1-9.10.

Singh T.N. 2011. Assessment of Coal Mine Overburden Dump Behaviour Using Numerical Modeling. Proceedings of Rock Mechanics, Fuenkajorn and Phien-wej (eds). pp. 25-36.

Sitharam T.G. and Nimbkar M.S. 2000. Micromechanical Modelling of Granular Material: Effect of Particle Size and Gradation. Journal of Geotechnical and Geological Engineering. 18: 91-117.

Snigdha Sushil and Vidya S. Batra. 2006. Analysis of Fly Ash Heavy Metal Content and Disposal in Three Thermal Power Plants in India. Published by Elsevier Ltd. pp. 1-4.

Sridharan A. Sossan T.G. Jose Babu T. and Abraham, B.M. 2006. Shear strength studies on soil-quarry dust mixtures, Geotechnical and Geological Engineering. 24: 1163-1179.

Takhelmayum Gyanen, Savitha A.L, Krishna Gudi. 2013. Laboratory Study on Soil Stabilization Using Fly Ash Mixtures, International Journal of Engineering Science and Innovative Technology (IJESIT). 2(1): 477-482.

Ugbe Felix C. 2011. Effect of Multicyclic Compaction on Cohesion in Lateritic Soils, Archives of Applied Science Research. 3(3): 115-121.

Ulusay R., Arikan F., Yoleri M.F. and Caglan D. 1995. Engineering Geological Characterization of Coal Mine Waste Material and an Evaluation in the Context of Back-Analysis of Spoil Pile Instabilities in a Strip Mine, SW Turkey. Journal of Engineering Geology. 40: 77-101.

WangLong, Xei Xiaogouang, Luan Hai. 2011. Influence of Compaction Methods on Shear Performance of Graded Crushed Stone. Journal of Materials in Civil Engineering. 23(10): 1483-1487.

Yoon Sungmin, Balunaini Umashankar, Yildirim Irem Z., Prezzi, Monica and Siddiki Nayyar Z. 2009. Construction of an Embankment with a Fly and Bottom Ash Mixture: Field Performance Study. Journal of Materials in Civil Engineering. 21(6): 271-278.