Shear Strength Behaviour of Geomaterials Prepared Using Expanded Polystyrene Beads

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ABSTRACT: Continuous growth in the various construction activities increases the demand for conventional construction materials; hence it has become necessary to look for alternative materials for construction work in the direction of sustainable development. In India, there are numerous industries which produce enormous quantities of stone dust and bottom ash which are generally treated as waste materials. In the present study, an attempt has been made for proper utilization of these materials in the field of geotechnical engineering. The shear strength characteristics of these materials by adding EPS beads in different percentages were investigated through shear box tests. Four different percentage of mix ratios 0.094, 0.188, 0.282 and 0.376 % were used apart from pure stone dust and bottom ash specimen in the study. The direct shear tests were carried out for four different normal stresses 50,100, 150 and 200 kPa. Effect of different mix ratios on density, stress – strain patterns and failure shear stress of these prepared geomaterials were investigated and the result are incorporated in the paper. The density of both bottom ash and stone dust geomaterials decreases with increasing mix ratio values. The density of bottom ash based geomaterial is lower than that of stone dust based geomaterial. The relationship between shear stress - strain was found to be non-linear for all mix ratios of both the geomaterials. The observed failure shear stress values decreased with increasing mix ratio values for both the geomaterials. For each mix ratio value, the failure shear stress values of these geomaterials were increased with increasing normal stresses.

Keywords: sustainable development, stone dust, bottom ash, expanded polystyrene beads, geomaterials.

1 INTRODUCTION

In recent years due to the continuous growth in construction activities the use of conventional materials like sand, aggregates in civil engineering construction industry is increasing day by day. Due to increasing demand of conventional materials, there has been lot of scarcity leading to environmental imbalance, and also leading to rise in the final cost of construction. The ever increasing demand of conventional materials made researchers to search for alternative materials to use successfully in the civil engineering projects. Hence in recent decades, efforts have been made to use industry by products such as fly ash, bottom ash, stone dust, etc. in civil engineering construction. Lightweight materials, in particular the expanded polystyrene (EPS) block geofoam also have been more widely used in the infrastructure rehabilitation and in the construction of new facilities such as roads and embankments.

Every year in India approximately 207 million ton total ash is generated. Bottom ash generation is 20% of total ash, approximately 41 million ton bottom ash generated per year (Behera et al., 2013). The current worldwide production of coal ashes is more than 700 million tons (Prakash and Shridharan, 2009). Bottom ash consists of non-combustible materials and it is collected from the bottom of the furnace. The utilization of coal ash not only solves its disposal problem but also provides an economic construction material. Ghafoori and Bucholc (1996) reported that bottom ash is used in road and construction filler material, as a foundation material, in noise barriers, as a capping layer on landfill sites. Stone dust is produced from the stone crushing industries. It has shown good results when it has been used as alternative conventional materials. According to Soosan et al. (2005) 200 million tons of stone dust is being generated every year in India. This material can be used in road works and many geotechnical applications effectively as it gradation does not suit the requirement of concrete works.
EPS beads made up of polystyrene and dissolved pentane (the blowing agent). EPS is non-biodegradable and hydrophobic in nature. It has closed cell structure which prevents absorption of water in it. It is highly compressible material available in different types for specific purpose. EPS beads can be used as lightweight fill material in construction of embankments, abutments and backfilling of retaining walls. Various studies have been carried out on EPS beads based light weight fill material by blending them with soil, fly ash, bottom ash and cement as a binder material (Yoonz et al. 2004; Wang and Miao, 2009 and Padade and Mandal, 2014, Ram Rathan Lal and Badwaik, 2015).
This paper reflects the results of direct shear test carried out on newly prepared geomaterials using bottom ash, stone dust and EPS beads. The direct shear tests were conducted as per IS 2720 (part 13) using standard shear box testing machine, accommodating the sample specimen of size 60 x 60 x 25 mm with the strain rate of 0.2 mm/min. The direct shear tests were carried out for four different normal stresses 50,100, 150 and 200 kPa. Effect of different mix ratios on density, stress – strain patterns and failure shear stress of these prepared geomaterials were investigated and the result are incorporated in the paper.

2 MATERIALS

For the preparation of geomaterials bottom ash, stone dust, EPS beads and cement were used. Table 1 shows the physical properties of bottom ash and stone dust. The density of EPS beads is 22 kg/m^3. The diameter of EPS beads are in the range of 2 to 3 mm, they are white in colour, well rounded having rough surface with tiny pores.

Table 1. Physical properties of bottom ash and stone dust

Properties	Bottom Ash	Stone Dust
Specific gravity (G)	1.91	2.6
Uniformity coefficient (C_u)	3.64	11.35
Coefficient of curvature (C_c)	0.971	1.85
Dry unit weight (kN/m^3)	13.7	19.5
Optimum Moisture Content (OMC) (%)	30	16

3 MIX RATIOS AND PREPARATION OF SPECIMEN

The mix ratio was defined as a ratio of two components by mass. In this paper mix ratio is the ratio of EPS beads to bottom ash and EPS beads to stone dust. Table 2 shows the mix ratios and weight of materials for both bottom ash and stone dust. These ratios were initially selected based on previous research studies (Liu et al. 2006, Badwaik et al. 2015 and Marjive et al. 2016). The mix ratios used in the study was 0.094%, 0.188%, 0.282% and 0.376% for bottom ash as well as stone dust.

The dry weight of the bottom ash W_{ba} required to make the specimen is calculated using formula $W_{ba} = \gamma_{dmax} \times V_{ba}$, where γ_{dmax} is the maximum dry unit weight of the fly ash and V_{ba} is the volume of the bottom ash. Volume of bottom ash V_{ba} is calculated by using formula $V_{ba}=V - V_b$, where V is total volume of specimen and V_b is volume of beads. Weight of the beads is calculated by using formula $W_b = \rho_b \times V_b$, where ρ_b is density of EPS beads. Volume of the water to be added is calculated with respect to dry weight of bottom ash ($V_w = W_{ba} \times OMC$). The dry bottom ash was firstly placed over a polyethene, then EPS beads were added and dry mixing was done to get uniform mix. Then water was added slowly according to the optimum moisture content and mixing was continued. Figure 1 shows the photograph of mixing of materials. After mixing, the compound mixture was cast into shear box and compacted. Then direct shear tests were conducted as per IS 2720 (part 13) using standard shear box testing machine, accommodating the sample specimen of size 60 x 60 x 25 mm with the strain rate of 0.2 mm/min. The direct shear tests were carried out for four different normal stresses 50,100, 150 and 200 kPa. Similar procedure was used to quantity of materials even for stone dust based geomaterial specimen.

Table 2. Mix ratios and weight of the samples

Mix Ratio	Weight of EPS beads (g)		Weight of Bottom Ash (g)	Weight of Stone Dust (g)	Weight of water (cc)	
	Bottom Ash	Stone Dust			Bottom Ash	Stone Dust
UR	-	-	123.3	175.5	37	28
0.094%	0.11	0.15	116.45	162.00	35	26
0.188%	0.21	0.28	110.39	150.38	33	24
0.282%	0.29	0.40	104.88	140.40	31	22
0.376%	0.38	0.50	99.92	131.66	30	21
UR = Unreinforced specimen (i.e.) pure Bottom ash /Stone dust specimen						

Figure 1. Mixing of materials

4 RESULTS AND DISCUSSION

The direct shear tests were carried out for four different normal stresses 50,100, 150 and 200 kPa. Density, shear stress – strain patterns and failure shear stress of geomaterials were investigated. From the results it was observed that above said parameters were significantly influenced by the mix ratio values and the normal stresses applied during the testing.

4.1 *Density*

Density was the important parameter for newly developed geomaterial and this was significantly influenced by the mix ratios values. The effect of mix ratios on density of bottom ash and stone dust geomaterial is shown in Figure 2. Relationship between density and mix ratio values were found to be linear. For each mix ratio value, with the addition of EPS beads in the range of 0.094 % to 0.376 %, the density of bottom ash mix geomaterial decreased from 1244kg/m^3 to 1055 kg/m^3 and for similar mix ratios the density of stone dust mix geomaterial is decreased from 1700 kg/m^3 to 1376 kg/m^3. This is significant improvement in terms of the density. For a particular mix ratio value bottom ash specimen has shown less density compared with stone dust specimen.

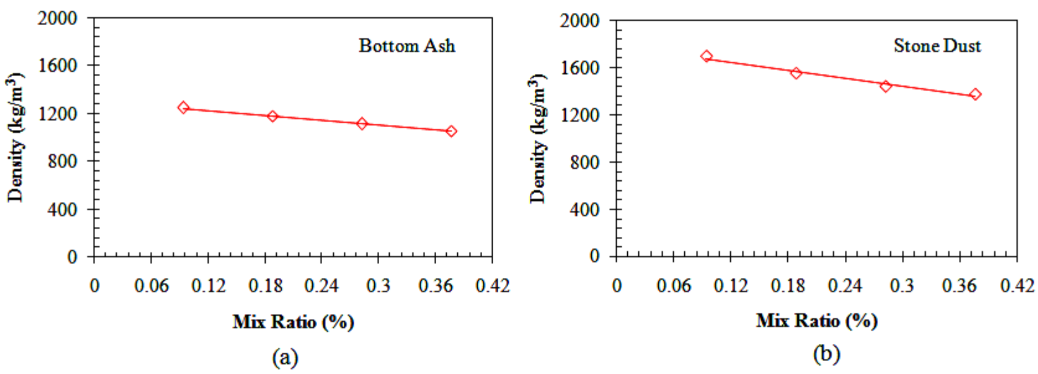

Figure 2. Relationship between mix ratios and density of (a) bottom ash and (b) stone dust

4.2 *Shear stress-strain pattern*

Figure 3 shows relation between shear stress and shear strain of bottom ash mix geomaterial for all normal stress values with different mix ratios including unreinforced specimen. The relationship between shear stress and shear strain was non-linear. The shear stress value was increased continuously without showing a peak shear stress value for all the possible conditions. No peak shear stress was observed even at 17 % shear stain. The failure shear stress was considered as shear stress corresponding to shear strain of 12%. For each mix ratio, the stiffness of geomaterial was increased with increasing normal stresses values. Similar trends were observed for stone dust geomaterial. Figure 4 shows relationship between shear stress and shear strain of stone dust geomaterial for all normal stress values with different mix ratios including unreinforced specimen. Figure 5 shows relation between shear stress and shear strain at normal stress of 50 kPa, 100 kPa, 150 kPa and 200 kPa of bottom ash for all the mix ratios. The relationship between shear stress and corresponding strain found to be non linear. The stiffness of the geomaterial was decreased with increasing mix ratio values for each normal stress value. Similar relationship was observed for even stone dust specimen.

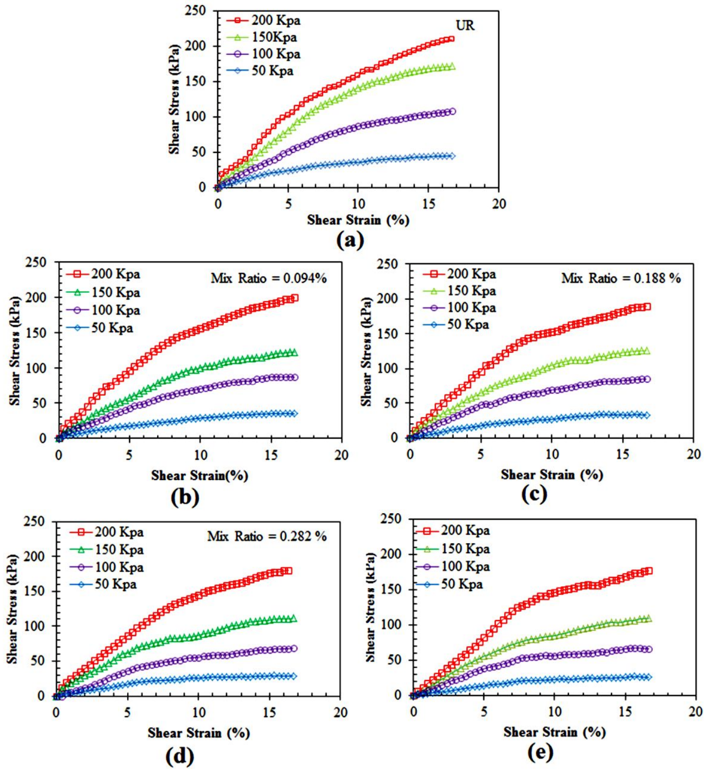

Figure 3. Relationship between shear stress and shear strain of bottom ash for all normal stresses of mix ratios (a) Unreinforced, (b) 0.094 %, (c) 0.188 %, (d) 0.282 and (e) 0.376 %

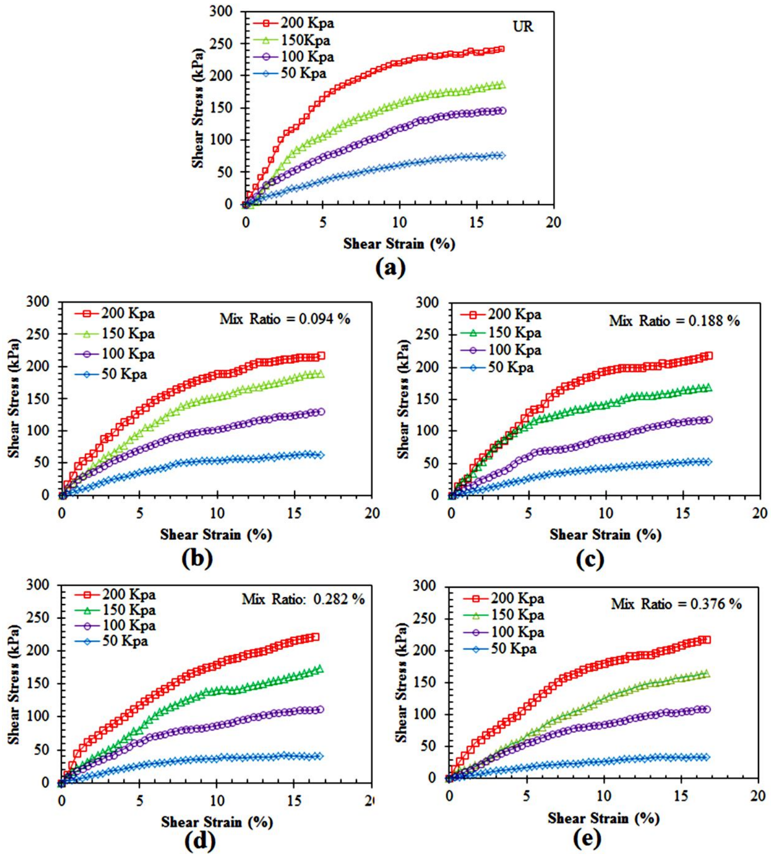

Figure 4. Relationship between shear stress and shear strain of stone dust for all normal stresses of mix ratios (a) Unreinforced, (b) 0.094 %, (c) 0.188 %, (d) 0.282 and (e) 0.376 %

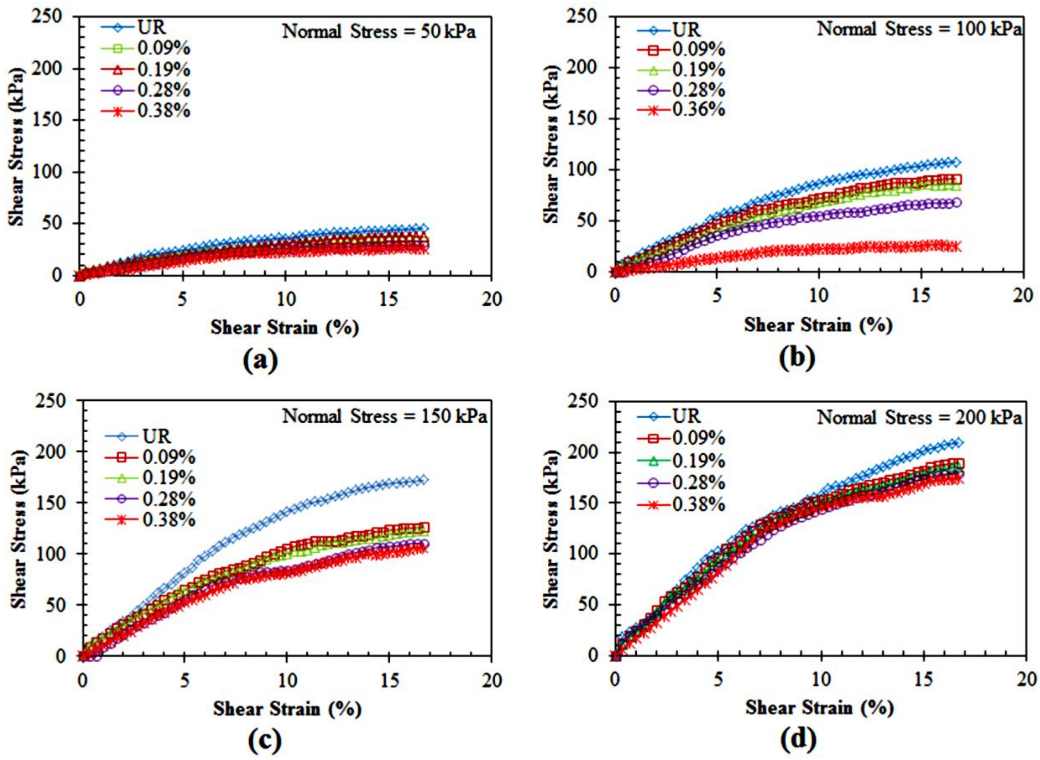

Figure 5. Relation between shear stress and shear strain at normal stress of (a) 50 kPa, (b) 100 kPa, (c) 150 kPa and (d) 200 kPa of bottom ash for all the mix ratios.

Table 2 gives the failure shear stress values for all mix ratios and normal stress values. The failure shear stress was considered as shear stress corresponding to shear strain of 12%. For both bottom ash and stone dust specimens the failure shear stress was found to be increased with increasing normal stress values for each mix ratio value. For each normal stress value increasing mix ratios results in decreasing failure shear stresses. The stone dust specimen has shown higher failure stresses compared with bottom ash specimen.

Table 2. Normal Stress and corresponding failure shear stress values

Mix Ratio (%)	Failure Shear Stress(kPa)							
	50 kPa		100 kPa		150 kPa		200 kPa	
	BA	SD	BA	SD	BA	SD	BA	SD
0.094	31.79	56.29	78.94	113.66	112.21	165.57	172.88	200.66
0.188	31.43	46.78	76.75	102.34	110.01	155.34	165.57	199.93
0.282	27.42	38.74	59.21	98.32	98.32	146.20	158.92	195.80
0.376	24.12	31.43	59.94	95.40	95.40	142.91	155.70	192.25
BA = Bottom Ash SD = Stone Dust								

5 CONCLUSION

A series of laboratory direct shear tests carried out on geomaterials prepared using bottom ash and stone dust by adding EPS beads. The tests were conducted with different mix ratios for different normal stress values. From the study following conclusions are made.
Most significant parameter of geomaterials was found to be its density. Relationship between density and mix ratio values were found to be linear. For each mix ratio value, with the addition of EPS beads in the range of 0.094 % to 0.376 %, about 18 % and 24 % reduction in density of geomaterials prepared with bottom ash and stone dust was observed. For a particu-

lar mix ratio value bottom ash specimen has shown less density compared with stone dust specimen. The failure shear stress increased with increasing normal stress for all mix ratio values. For each mix ratio and normal stress value stone dust specimen shown higher failure shear stress compared with bottom ash specimen. Non linear relationship was observed between shear stress and shear strain for all the mix ratios. The stiffness of the geomaterials was observed to be decreasing with increasing values of mix ratio.

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