

# Behaviour of Reinforced Soil under Unconfined Axial Compression Loading

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**Abstract**—This paper pertains the unconfined compressive strength test results of newly developed geomaterial prepared using blast furnace slag, plastic strips cut from used and waste plastic water bottle, EPS beads and locally available soil. The increase in production of slag, plastic waste and their disposal in an eco-friendly manner is a matter of concern. This paper briefly describes the suitability of slag and plastic waste to be used in geotechnical engineering applications as a way to minimize their disposal in the environment and in the direction of sustainable development. The tests were carried by adding EPS beads with different mix proportions. The plastic strips of different aspect ratios 0.05, 0.1, 0.15 and 0.2 were added with different percentages of 0.5 %, 1 %, and 1.5 %. Slag was added in two different percentages of 2.5 % and 5 %. The mix ratio percentages 0.05, 0.1, 0.15 and 0.2 were used in the study. Series of unconfined compression tests were performed on newly developed geomaterial. Test results indicate that compressive strength increases with increase in plastic strips up to aspect ratio of 0.15 and then decreases for aspect ratio of 0.2. The compressive strength values were decreased with increasing mix ratio values. The initial tangent modulus and density of the geomaterial decreased with increasing mix ratio values. Stiffness of the geomaterial increased with increase in slag percentages.

**Keywords**-compressive strength; geomaterial; blast furnace slag; plastic strips; sustainable development; aspect ratio.

## I. INTRODUCTION

Over the last few decades there has been a steady increase in the use of plastic products resulting in an astonishing rise in plastic waste in the municipal solid waste in major cities of India. Lot of efforts need to be taken to utilize this plastic waste in some or other ways. In India approximately 8 million tonnes plastic products are consumed every year [1]. Out of which 60 % of plastic waste by weight is collected for recycling and 40 % by weight of plastic waste remains uncollected. This 40% plastic is responsible for environmental hazards. According to International Bottled Water Association, sales of bottled water have increased by 500% over the last decade. 1.5 Million Tonnes of plastic are used to bottle water every year. Unfortunately the recycling process is messy and inefficient reported by [2]. Inclusion of these waste plastic bottle strips into the soil causes modification and improvement in the engineering behaviour of soil. The experimental studies to know the CBR behaviour of waste plastic strips reinforced stone dust for the effective utilization of stone industries by product in applications of civil engineering was performed by [3]. CBR tests were conducted on plastic strip reinforced flyash to understand the behaviour and to know its suitability in the pavement construction by [4]. Experimental studies have been conducted by [5] for the utilization of coal combustion by product bottom ash based material reinforced with plastic strips cut from the used and wasted plastic water bottles and EPS beads.

Slag is a by-product generated during manufacture of pig iron and steel. The slag produced at blast furnace during pig iron manufacturing is called blast furnace slag. Around 10 million tonnes blast furnace slag is currently generated in the country as per the report of the Working Group on Cement Industry for the 12<sup>th</sup> plan [6]. Lot of efforts have been taken and are underway to use this by-product as useful geotechnical material. Many researchers carried out experimental investigations to find the suitability of blast furnace slag in the field of civil engineering applications [7 - 12].

The expanded polystyrene (EPS) beads are produced a step before the production of blocks, that is the blocks are made by fusion of beads [13]. They are non-biodegradable and chemically inert in both soil and water. According to [14] EPS beads are hydrophobic in nature and it has closed cell structure that prevents absorption of water in it. The EPS is a highly compressible material available in different types for specific purposes reported by [15]. The mechanical characteristics of light-weight soils consisting of Expanded Polystyrene (EPS), dredged clays, and cement through both unconfined and triaxial compression tests was studied by [16]. They have reported that the strain at failure in triaxial test was 39 % less than that in unconfined compression test. The

unconfined compressive strength of the lightweight fillmaterial which was prepared by using soil with Polystyrene Pre-Puff (PSPP) beads and cement increases considerablywith increase in cement to soil ratio [17]. It was reported by [18] that the geomaterial prepared by using EPS beads and bottom ashwas light inweight compared with conventional fill materials and it can be used as a substitute to conventional fill materials on soft soils. The experimental studies to know the behaviour of newly developed construction material under compression loading using stone industries byproduct stone dust and EPS beads was conducted by [19].

The present study mainly focuses on the unconfined compression behaviour of newly developed geomaterial. Series of unconfined compression tests have been conducted on geomaterial specimen of size 38 mm in diameter and 76 mm in height and test results are incorporated in the paper. To prepare the geomaterial, plastic strips and slag were added to soil in percentage of 0.5 %, 1 %, 1.5 % and 2.5 %, 5 % respectively. Different aspect ratios (AR) 0.05, 0.1, 0.15, 0.2 and mix ratios 0.05 %, 0.1 %, 0.15 %, 0.2 % were used in the experimental program.

## II. MATERIALS

Four different materials were used to prepare the geomaterial namely blast furnace slag, strips cut from the used and waste plastic water bottles, expanded polystyrene beads and locally available soil. Blast furnace slag was procured from Bhilai Steel Plant, Bhilai, Chhattisgarh, India in moist state. The physical properties of blast furnace slag were given in Table I.

Table I Physical properties of blast furnace slag

Properties	Value
Specific gravity (G)	2.24
D <sub>10</sub> (mm)	0.3
D <sub>30</sub> (mm)	0.5
D <sub>60</sub> (mm)	0.7
Uniformity coefficient (C <sub>u</sub> )	2.33
Coefficient of curvature(C <sub>c</sub> )	1.19
Coarse size sand (%)	2
Medium size sand (%)	78
Fine size sand (%)	20
Silt size (%)	3
Maximum dry density ( $\gamma_{dmax}$ ) (kN/m <sup>3</sup> )	1.32
Optimum moisture content (%)	10
Bulking(%)	29.03

X-Ray florescence spectrometer test was performed on blast furnace slag to know the various chemical compounds. Table II gives the chemical compounds of blast furnace slag. Plastic strips which were used in the experimental program were cut from the used and waste plastic water bottles. Four different aspect ratios 0.05 (1 × 20 mm), 0.1 (2 × 20 mm), 0.15 (3 × 20 mm) and 0.2 (4 × 20 mm) were used. Aspect ratio (AR)in the present study is defined as ratio between width and length of plastic strip.

Table II Chemical properties of blast furnace slag

Compound	Value ( % )
Al <sub>2</sub> O <sub>3</sub>	14.71
CaO	40.07
Fe <sub>2</sub> O <sub>3</sub>	1.23
K <sub>2</sub> O	0.37
MgO	7.12
MnO	0.31
Na <sub>2</sub> O	0.21
SiO <sub>2</sub>	33.21
SO <sub>3</sub>	2.23
TiO <sub>2</sub>	0.54

Fig.1 shows different sizes of plastic strips used in the experimental program. The density of EPS beads used in the present study is  $16 \text{ kg/m}^3$  and they are appeared to be spherical in shape. The diameter of the EPS beads was in the range of 2 to 3 mm. Locally available soil was used in the experimental study. The physical properties of soil were given in Table 3.

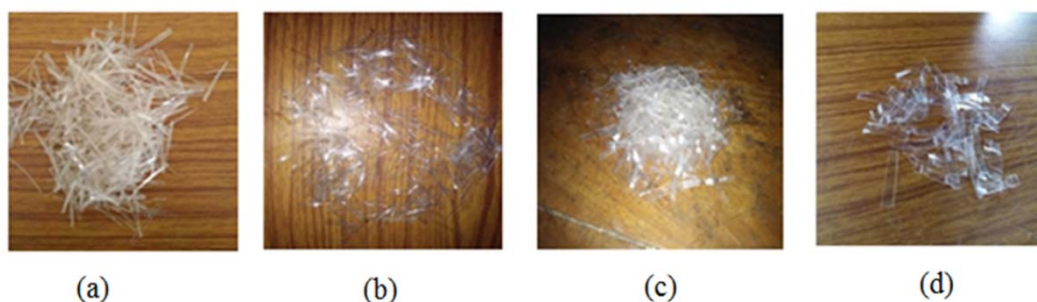


Fig.1. Photograph of plastic strips cut from used and waste plastic water bottle(a) aspect ratio= 0.05 (1 × 20) mm, (b) aspect ratio= 0.1 (2 × 20) mm, (c) aspect ratio= 0.15 (3 × 20) mm and (d) aspect ratio= 0.2 (4 × 20) mm

Table III Physical properties of soil

Properties	Value
Specific gravity (G)	2.52
Liquid limit (%)	41
Plastic limit (%)	27
Sand size (%)	9
Silt size (%)	62
Clay size (%)	28
Maximum dry unit weight ( $\gamma_{dmax}$ ) (KN/m <sup>3</sup> )	15.85
Optimum moisture content (%)	26

### III. EXPERIMENTAL PROGRAM

The experimental program was planned with an objective to understand and investigate the effect of inclusion of EPS beads, plastic strips cut manually from used and waste plastic water bottles and blast furnace slag in soil and to determine the unconfined compressive strength. Series of unconfined compression tests was carried out in accordance with [20] on newly developed geomaterial. The effect of different mix ratios, aspect ratios, slag and plastic strip percentage on compressive strength, density and initial tangent modulus of newly developed geomaterial was investigated and presented in the paper.

#### A. Mix Ratios and Preparation of Specimen

In the present study, mix ratio (MR) is defined as the ratio between weight of EPS beads and soil. It was expressed in terms of percentages. The dry weight of the silty clay  $W_b$  required to make the specimen was calculated using formula  $W_b = \gamma_{dmax} \times V_b$  where  $\gamma_{dmax}$  is the maximum dry unit weight of soil and  $V_s$  is its volume. Volume of dry soil  $V_s$  was calculated by using the formula  $V_s = V - (V_{beads} + V_{slag} + V_{strips})$  where  $V$  is the total volume of the specimen that is 86.2 cc and  $V_{beads}$  is volume of beads,  $V_{slag}$  is volume of slag and  $V_{strips}$  is volume of plastic strips. To achieve the initial mix ratio value of 0.05 %, volume of beads, slag and strips were assumed as 4, 1 and 1 cc respectively. Weight of the beads was calculated by using the formula  $W_{beads} = \rho_{beads} \times V_{beads}$ , where  $\rho_{beads}$  is the density of EPS beads. The weights of plastic strips and slag were calculated based on their percentage taken with respect to soil. Volume of the water to be added was calculated with respect to the dry weight of soil  $V_w = W_b \times OMC$ , where OMC is the optimum moisture content. Table IV gives the experimental program.

Table IV Experimental program

Mix Ratio (MR) (%)	Plastic Strip (PS/SC) (%) Aspect Ratios : 0.05,0.1,0.15,0.2	Slag (S/SC) (%)
0.05	0.5;1.0;1.5	2.5;5.0
0.1	0.5;1.0;1.5	2.5;5.0
0.15	0.5;1.0;1.5	2.5;5.0
0.2	0.5;1.0;1.5	2.5;5.0

All the ingredients required for the preparation of the specimen were measured with the help of electronic weighing balance. EPS beads, slag and plastic strips were added to soil as per the calculation and then they were dry mixed. Then all the materials were mixed by adding required quantity of water gradually. This mixture was then put in the mould and compacted. The specimen was then extracted using extractor. The specimen prepared having diameter of 38 mm and 76 mm in height. Fig. 2 shows mixing and extraction of prepared geomaterial specimen.



Fig.2. (a) Mixing of all materials (b) Extraction of prepared geomaterial specimen

### B. Test Procedure

The initial length, diameter and weight of the specimen was measured and the specimen was placed at the bottom plate of the loading device. The upper portion of the specimen was adjusted in such a manner that it should make contact with the proving ring through a loading plate. The unconfined compressive strength tests were performed with the strain rate of 1.25 mm/minute. To complete the experimental program overall 96 specimens were tested and the results are presented in the paper. To check the reproducibility of specimens for each mix ratios one specimen was prepared and tested. Repeatability test results found encouraging to a variation of 4 to 7 %.

## IV. RESULTS AND DISCUSSIONS

### A. Failure Pattern

Under unconfined compressive load, the failure patterns of the prepared geomaterial specimen were observed for different mix ratio values, plastic strip percentages and slag with different aspect ratios. For lower strip percentages bulging failure was observed. The bulging was predominantly at middle portion of the specimen. As the strip content increased, the specimen has not shown considerable bulging during failure. The failure patterns consist of vertical cracks starting from the mid height of the specimen and continued upto bottom of the specimen. Moderate bulging was shown at bottom as if it is getting compressed at bottom during failure. All the specimens were failed at a failure axial strain of 2 % to 7 %. Fig. 3 shows failure pattern of prepared geomaterial at lower strip percentage and higher strip percentage.

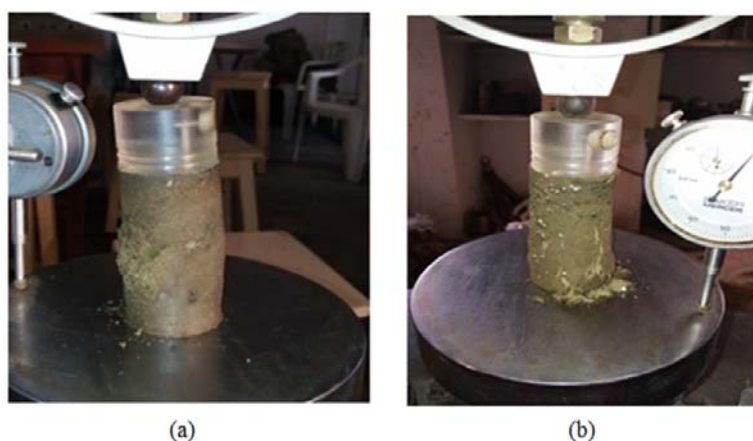


Fig.3. Failure pattern at (a) Lower strip percentage (b) Higher strip percentage

### B. Density

For newly developed geomaterial density was most important parameter and it was significantly influenced by the mix ratios as well as slag content. Effect of mix ratios on the density of the geomaterial was shown in Fig. 4. It can be seen that the density of geomaterial decreases with increase in mix ratio values which indicates that the material becomes lighter. The minimum and maximum density was found out to be 1050 kg/m<sup>3</sup> and 1727 kg/m<sup>3</sup>. The density values achieved in the present study was lesser than the pure clay density which lies between 1700-1900 kg/m<sup>3</sup> as reported by [17]. This is significant improvement in terms of density values of newly developed geomaterial.

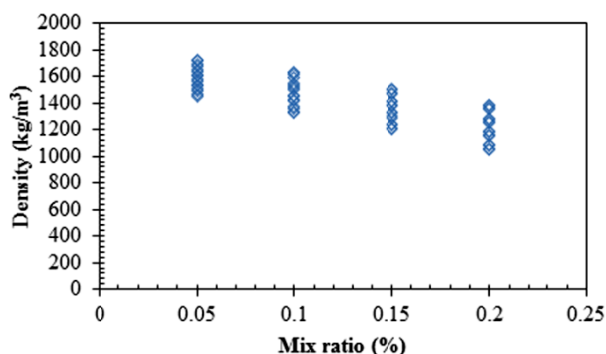


Fig.4. Effect of mix ratios on the density of geomaterial

### C. Compressive Strength

Linear relationship was observed between compressive strength and plastic strip percentage. Fig. 5 shows the relationship between plastic strip percentage and compressive strength for mix ratio 0.10 and different S/BCS percentages. For a particular plastic strip percentage and for each slag percentage the compressive stress of the geomaterial increased with increasing AR values. This trend was continued upto AR 0.15 later for AR 0.2 the compressive strength values of geomaterial was decreased. Compressive strength was found to be increased with increasing plastic strip percentage for both slag percentage values. When slag percentage was 5.0 % shown higher compressive strength values in comparison with slag percentage of 2.5 %. Steeper slope was observed between compressive strength and plastic strip percentage when slag percentage was 2.5 % while gentle slope was observed when 5.0 %. Similar trend was observed for all the mix ratios.

Fig. 6 shows the relationship between mix ratio and compressive strength for all the aspect ratios, plastic strip percentage was 1.0 % and for both slag percentage values. Linear relationship was observed between compressive strength and mix ratio values. For each aspect ratio the compressive strength of geomaterial decreased with increasing mix ratio values. The variation in compressive strength for all aspect ratio for each slag percentage, plastic strip percentage was minimum when mix ratio 0.2 % and maximum when mix ratio 0.05%. The compressive strength value from mix ratio 0.05 % starts converging towards mix ratio 0.2 %. Maximum and minimum compressive strength values for mix ratio 0.05 % was 708 kPa and 352 kPa respectively while the maximum and minimum compressive strength values for mix ratio 0.2 % was 170 kPa and 98 kPa respectively.

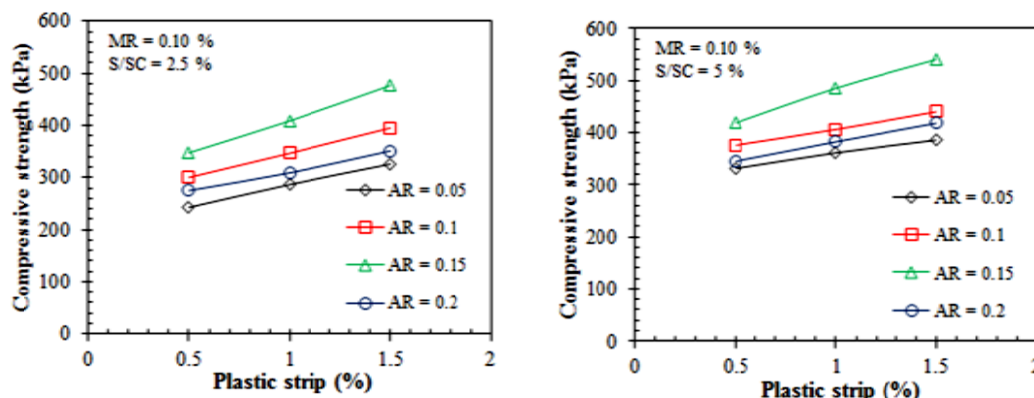


Fig. 5 Relation between plastic strip percentage and compressive strength for mix ratio 0.10 and both slag percentages

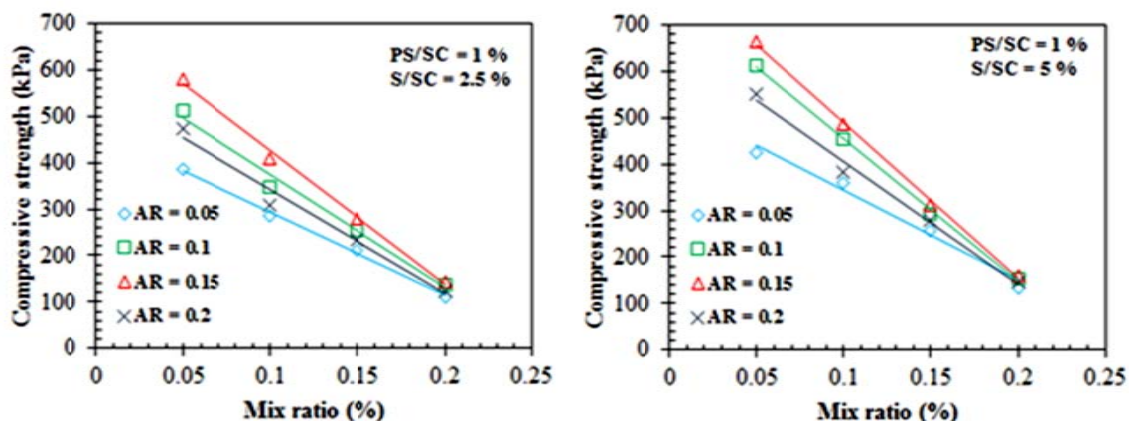


Fig. 6 Relation between mix ratio and compressive strength for all the aspect ratios, plastic strip percentage 1 % and both slag percentages

Table V gives the peak compressive stress values along with corresponding axial strain (%) values for all ratios used in the experimental program. By keeping all the parameters constant as the mix ratio increases the unconfined compressive strength decreases and also the corresponding strain. Whereas for each mix ratio increasing the percentages of plastic strip the unconfined compressive strength and its corresponding axial strain also increases. For each mix ratio and plastic strip percentages increasing the aspect ratio of strip the unconfined compressive strength and its corresponding axial strain was reduced. For a particular plastic strip percentage with each mix ratio and aspect ratio increasing the slag percentage the unconfined compressive strength and corresponding axial strain at failure was increased. The maximum value of stress and its corresponding axial strain was 708.12 kPa and 6.84 (%) respectively whereas the minimum value of compressive stress and axial strain was 98.29 kPa and 2.18% respectively. Fig. 7 shows the relation between compressive strength and density of newly developed geomaterial. The correlation between density and compressive strength was well fitted in a power curve and can be expressed by

$$\sigma = 2E-09\rho^{3.516}$$

where,  $\sigma$  = compressive strength in kPa and  $\rho$  = density in  $\text{kg/m}^3$

#### D. Stress Strain Pattern

1) *Effect of Strip Content and Slag*: Fig. 8 shows the stress strain characteristics of reinforced soil for different percentage of strips 0.5 %, 1 % and 1.5% for each mix ratio at various aspect ratios with different percentage of slag 2.5 % and 5.0%. For each mix ratio and for a particular aspect ratio and slag percentage, increasing the plastic strip content tends to increase the stiffness of the specimen. The unconfined compressive stress and corresponding axial strain (%) at failure was also increased. For each mix ratio values, for a particular aspect ratio and plastic strip percentages increasing the slag percentages the stiffness of the specimen was increased.



Table V Peak compressive stresses and corresponding axial strain of different strip ratios at various strips and slag content

Mix Ratio (MR) (%)	Plastic Strips (PS/SC) (%)	Peak Compressive Stress (kPa) and Corresponding Axial Strain (%)							
		Aspect Ratio							
		0.05		0.1		0.15		0.2	
		Slag (S/SC) (%)		Slag (S/SC) (%)		Slag (S/SC) (%)		Slag (S/SC) (%)	
		2.5	5.0	2.5	5.0	2.5	5.0	2.5	5.0
0.05	0.5	352.65 (3.95)	380.74 (4.02)	428.84 (4.21)	554.21 (4.25)	480.26 (4.50)	610.12 (5.01)	408.35 (4.05)	510.11 (4.89)
	1.0	385.6 (4.20)	425 (4.80)	525.36 (5.00)	612.23 (5.53)	581.15 (5.89)	665 (6.01)	475 (5.65)	552.12 (5.82)
	1.5	418.54 (5.20)	480.43 (5.30)	619.56 (5.62)	650.00 (5.84)	698.31 (6.57)	708.12 (6.84)	509.00 (6.00)	605.01 (6.25)
0.1	0.5	242.68 (3.15)	331.89 (3.42)	300.10 (3.87)	375.72 (3.94)	347.41 (4.30)	418.43 (4.70)	275.08 (3.42)	344.92 (3.62)
	1.0	286.56 (3.37)	361.15 (3.75)	346.5 (3.95)	406.6 (4.21)	408.62 (4.39)	485.8 (4.89)	309.5 (3.16)	382.3 (4.21)
	1.5	325.75 (3.95)	385.43 (4.18)	395.02 (4.21)	440.02 (4.31)	476.69 (4.62)	540.13 (5.00)	351.35 (3.68)	418.65 (4.47)
0.15	0.5	185.20 (2.63)	241.41 (3.16)	227.34 (2.89)	266.34 (3.43)	254.55 (3.24)	288.36 (3.78)	209.76 (2.89)	255.34 (3.12)
	1.0	211.19 (3.16)	258.81 (3.68)	255.42 (3.63)	292.70 (3.89)	279.5 (3.93)	311.81 (4.21)	234.16 (2.63)	278.07 (3.16)
	1.5	241.65 (3.42)	225.20 (3.68)	275.94 (3.66)	310.11 (3.94)	301.33 (4.01)	329.23 (4.38)	263.57 (2.89)	292.15 (3.63)
0.2	0.5	98.29 (2.18)	115.63 (2.43)	125.38 (2.33)	137.42 (2.78)	133.63 (2.69)	149.99 (2.99)	116.01 (2.48)	131.28 (2.63)
	1.0	109.46 (2.34)	135.25 (2.48)	138.16 (2.94)	152.63 (3.21)	144.2 (3.10)	160.68 (3.43)	125.21 (2.42)	146.53 (3.15)
	1.5	115.24 (2.42)	151.28 (2.58)	148.31 (2.83)	162.43 (3.15)	153.23 (2.93)	170.83 (3.20)	137.03 (2.86)	157.57 (3.15)

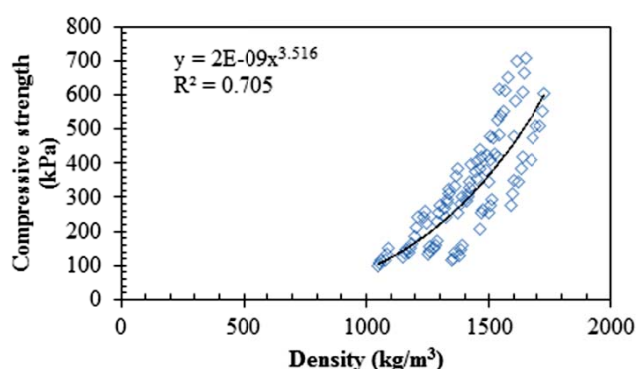


Fig. 7 Relation between density and compressive strength

2) *Effect of Aspect ratio:* Fig.9 shows the compressive stress- axial strain behaviour of reinforced soil with different aspect ratio for each mix ratio value, particular strip content and slag percentage. It was observed that for each mix ratio value plastic strip content and for a particular slag percentage increasing the aspect ratio value there is increased in the unconfined strength of the specimen along with the failure axial strain. This trend was continued upto AR 0.15 and then for AR0.2 the unconfined compressive stress and axial strain was decreased. Similarly the stiffness of the specimen was increased up to AR 0.15 and then the stiffness was reduced for AR 0.2. Non-linear relationship was observed between compressive stress and axial strain.

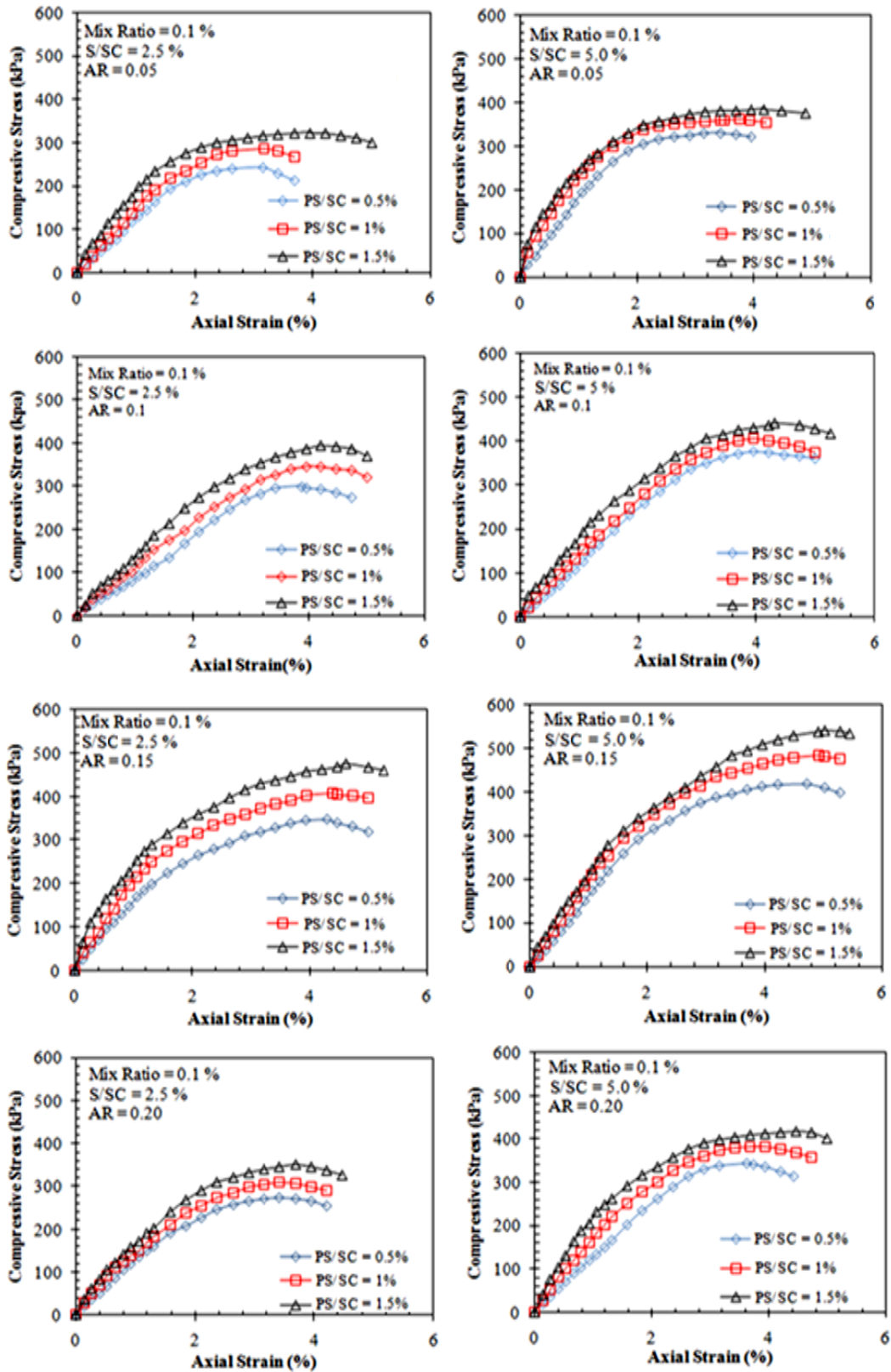


Fig. 8 Relationship between compressive stress and axial strain of reinforced soil with different percentage of strips and slag for mix ratio 0.1%



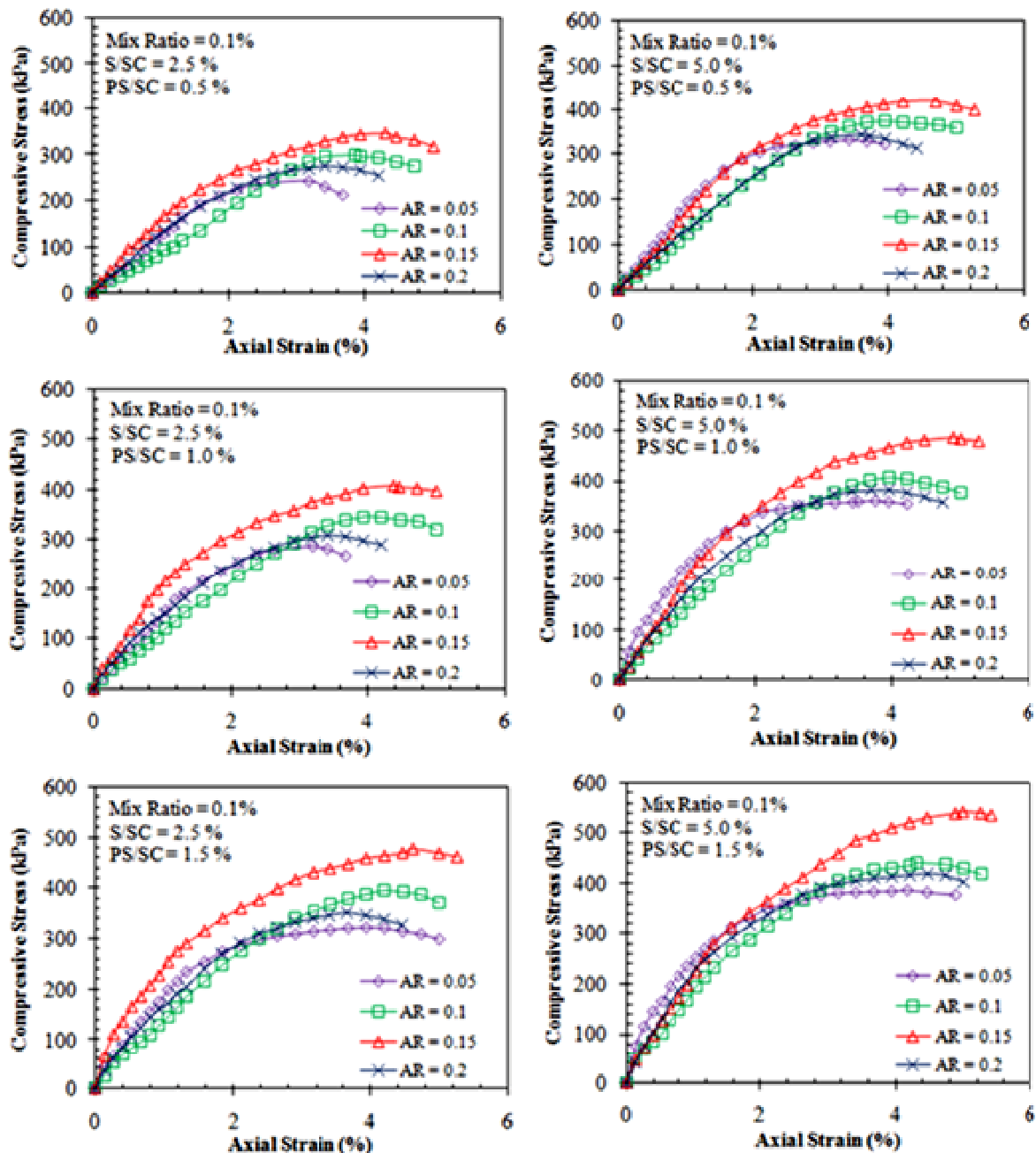


Fig. 9 Relationship between compressive stress and axial strain of reinforced soil for mix ratio 0.1 % and particular plastic strip content and slag percentages

### E. Initial Tangent Modulus

The initial tangent modulus was the slope of the tangent line to the origin of compressive stress and strain curves. It is used to compare the stiffness of material. Higher compressive strength tends to be associated with higher initial tangent modulus. Fig.10 shows the correlation between compressive strength and initial tangent modulus of the studied geomaterial. It can be seen that the initial tangent modulus values are in the range of 4-57 MPa. The initial tangent modulus values were lower than those of lightweight fill material which lies between 79 to 555 MPa as reported by [17] and higher than those for the EPS geofoam block which lies between 2.2 and 11.4 MPa as reported by[21- 23]. The initial tangent modulus values of the present study are in the range of geomaterial density reported by[18]. The correlation between initial tangent modulus ( $E_i$ ) and compressive strength ( $\sigma$ ) can be expressed as  $E_i = 0.44\sigma + 4.63$  where,  $\sigma$  = compressive strength in kPa and  $E_i$  = Initial tangent modulus in MPa.

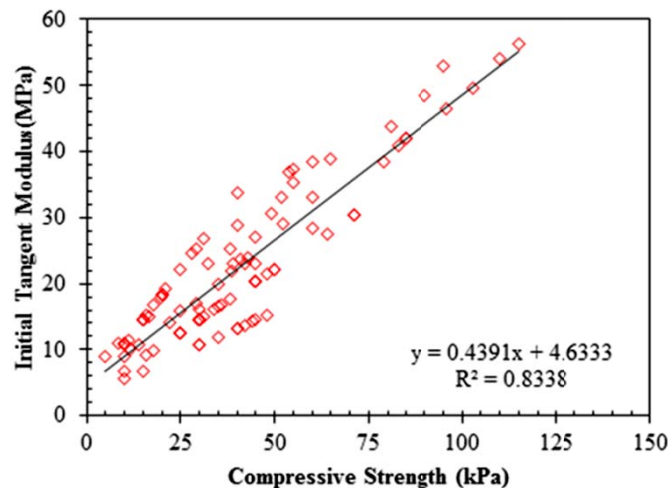


Fig.10 Correlation between compressive strength and initial tangent modulus

## V. CONCLUSIONS

A series of unconfined compressive tests were carried out on the plastic strip reinforced soil along with blast furnace slag to understand its behaviour. Different aspect ratios, percentages of plastic strips and percentages of slag were used in the study. From the study carried out, following conclusions are made.

- The density of geo-material was significantly influenced by mix ratios. It decreases with increase in mix ratio values thus the material becomes lighter. The minimum and maximum density values achieved in present study was  $1050 \text{ kg/m}^3$  and  $1727 \text{ kg/m}^3$  respectively.
- For each mix ratio, for particular plastic strip and slag percentages, with increase in aspect ratio values the unconfined compressive strength along with failure axial strain increased up to aspect ratio 0.15 and then it decreased for aspect ratio 0.2. The compressive strength was in the range between 708.12 kPa and 98.29 kPa.
- Linear relationship was observed between compressive strength and plastic strip percentage. The variation in compressive strength was minimum when mix ratio 0.2 % and maximum when mix ratio was 0.05 %. The compressive strength value from mix ratio 0.05 % starts converging towards mix ratio 0.2 %. Slag percentage of 5.0 % has shown higher compressive strength values in comparison with 2.5 %.
- The initial tangent modulus of the geomaterial increased with compressive strength. The initial tangent modulus was in the range of 4 to 57 MPa with respect to mix ratios.
- Nonlinear relationship was observed between compressive stress and axial strain. The stiffness of the material was increased with increasing plastic strip percentage and slag percentage.

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