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Behaviour of Plastic Strip Reinforced Blast Furnace Slag under Triaxial Loading Condition

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Abstract: Most of the civil engineering constructions are going-on by using conventional materials such as sand, other natural minerals and metals etc. But the availability of these materials is limited since the production due to natural cycle is slow. Thus, there is need of material that can replace such conventional material. Blast furnace slag is one of such material which can replace the conventional materials. In this present experiment, the study related to the Blast Furnace Slag (BFS) and plastic waste bottles used in civil engineering works as a way to minimize their disposal and in the direction of sustainable development. The sample was prepared by using Blast Furnace Slag (BFS) and plastic strips cut manually from used and waste plastic water bottles with four different Aspect Ratios (AR) 1, 2, 3 and 4. The experiments were conducted with the different mix ratio percentages 1, 2 and 3. The plastic strips of different aspect ratios 1, 2, 3 and 4 were added with different mix ratios 1%, 2% and 3% with respect to weight of blast furnace slag. Series of un-drained un-consolidate triaxial tests for cell pressure 100 kPa, 200 kPa and 300 kPa were performed on reinforced blast furnace slag. From the test results we observed that deviator stress increases with increase in aspect ratios and mix ratios. Also the shear strength parameters were found to be influenced with the change in aspect ratios and mix ratios.

Keywords: Blast furnace slag, Plastic strips, triaxial tests, aspect ratios, mix ratios, deviator stress.

INTRODUCTION

Blast Furnace Slag (BSF) is a non-metallic by-product obtained during the manufacturing process of pig iron and steel. The chemical composition of a slag varies considerably depending on the composition of the raw materials in the iron production process. The main components of blast furnace slag are CaO (30-50%), SiO_2 (28-38%), Al_2O_3 (8-24%), and MgO (1-18%). In general increasing the CaO content of the slag results in raised slag basicity and an increase in compressive strength. The MgO and Al_2O_3 content show the same trend up to respectively 10-12% and 14%, beyond which no further improvement can be obtained. Different forms of slag products are manufactured depending on the method used to cool the molten slag. These products include air-cooled BFS, expanded or foamed slag, pelletized slag, and Granulated Blast Furnace Slag (GBFS)[1] (TFHRC 2004). In country like India, the utilisation of blast furnace slag and its disposal in environment friendly manner is of foremost concern. As per the report of the Working Group on Cement Industry for the 12th plan, around 10 million tonnes blast furnace slag is currently generated in country. The blast furnace slag can be utilised in bulk in geotechnical engineering applications such as backfill for retaining wall, use as sub base and other foundation layers. In this direction, over the past few years, many researchers have worked extensively to convert this wasteful by-product useful in civil engineering applications [2,3,4]. Plastic are the non-biodegradable materials made up of long chain of hydrocarbon with additives, which can be moulded into finished product. Since plastics are non-biodegradable it remains on the planet as a waste material for many years. According to Central Pollution Control Board (2012), in India approximately 8 million tonnes plastic products are consumed every year. And from this 60% by weight, plastic waste collected and 40% by weight, plastic waste remains uncollected. This 40% plastic is responsible for environmental hazards. According to

(a) (b) (c) (d)

Fig. 1 Photographs showing plastic strips (a) 2 × 2 mm, (b) 4 ×2mm (c) 6 × 2 mm and (d) 8 × 2 mm

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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. This waste plastic can be used in geotechnical engineering for modification and improvement of engineering behaviour of soil. Earlier researches have been carried out for the use of plastic waste as reinforcement. The plastics strip as reinforcement has been utilized in wide areas of geotechnical engineering for enhancing the strength and stability of soil. For such studies different aspect ratios and different mix ratios were used for the experiment conducted [5,6,7,8,9]. For the study of reinforced soil specimen, triaxial tests are most apt tests. Triaxial tests were performed in earlier researches to understand the behaviour of reinforced soil [10,11,12,13,14]. In the present study, an attempt has been made to study the behaviour of plastic strip reinforced blast furnace slag behaviour under triaxial loading conditions. For this, series of triaxial tests are performed on dry specimen of unreinforced blast furnace slag and also on dry blast furnace slag with reinforcement of plastic strips. The strength parameters are calculated under three different cell pressure i.e. 100 kPa, 200 kPa and 300 kPa. The plastic reinforcement was provided in random fashion. The results of 39 triaxial tests are cited in this paper.

Characterization of Materials

Blast furnace slag
The blast furnace slag is procured in moist state from Bhilai Steel Plant, Chhattisgarh, India and is use in study.

Physical properties
The physical properties of blast furnace slag are given in Table I.

Chemical properties
X-ray fluorescence test is performed by using X- ray fluorescence spectrometer to know the percentage of basic chemical constitute of the blast furnace slag at SAIF, IIT Mumbai. The basic chemicals present in the blast furnace slag are CaO (40.07%), SiO_2 (33.21%), Al_2O_3 (14.71%), MgO (7.12%), SO_3 (2.23%), Fe_2O_3 (1.23%), TiO_2 (0.54%), K_2O (0.37%), MnO (0.31%) and Na_2O (0.21%).

Table I Physical property of blast furnace slag

Properties	Values
Specific gravity (G)	2.24
Grain size distribution	
D_{10} mm	0.3
D_{30} mm	0.5
D_{60} mm	0.7
Uniformity coefficient (C_u)	2.33
Coefficient of curvature (C_c)	1.19
Coarse size sand (%)	2
Medium size sand (%)	78
Fine size sand (%)	20
Silt size (%)	3
Compaction characteristics	
Maximum dry density (γ_{dmax})	1.32
Optimum moisture content (%)	10
Bulking (%)	29.03

Discrete Reinforcement
The discrete reinforcement provided in the experiment is made up of locally available used and wasted plastic water bottle. The reinforcement is formed for four different aspect ratios i.e. 1, 2, 3 and 4.The bottles were cut along the length to form 2 mm wide strip. The aspect ratios were obtained by keeping width of 2mm as constant and varying length of the strips. The long strips were cut to form strip of size 2 x 2 mm, 4 x 2 mm, 6 x 2 mm, 8 x 2 mm, Fig.1

(a) (b) (c) (d) (e)

Fig. 2 Photograph showing failure pattern at (a) unreinforced blast furnace slag and reinforced blast furnace slag for mix ratio 1% with varying aspect ratio i.e. (b) AR 1, (c) AR 2, (d) AR 3 and (e) AR 4.

Experimental program

The experimental program was planned with an objective to understand the behaviour of dry blast furnace slag under both conditions i.e. unreinforced and reinforced with plastic strips under triaxial loading conditions [15] and also to study the effect of different mix ratios of discrete plastic strip reinforcement on shear strength parameters. Apart from the unreinforced blast furnace slag, the triaxial tests were performed on plastic strips reinforced blast furnace slag with different aspects ratios i.e. 1, 2, 3 and 4, and also with different mix ratios of reinforcement i.e. 1%, 2% and 3%.

Preparation of specimen

The calculations of the mix proportions for the preparation of the specimen is based on the previous studies carried out as per [16]. The dry weight of the blast furnace slag W_{BFS} required to make specimen is calculated using the formula $W_{BFS}=\gamma_{dmax}V$, where γ_{dmax} is the maximum dry unit weight of blast furnace slag and V is the volume of the blast furnace slag sample. For reinforced sample, using suitable mix ratios, the quantity of blast furnace slag and the plastic reinforcement is calculated using the formula $W_T=W_S + W_{BFS}$, where W_T is the total weight of the sample and W_S is the weight of plastic strips. The weight of dry blast furnace slag and plastic strips were measured as per the calculations of mix ratio. Now in dry blast furnace slag, plastic strips are added and are mixed thoroughly. The dry sample is then poured through the funnel from a constant height of 15 cm in the mould which is on the pedestal of the triaxial cell using rainfall technique. The density of the sample achieved through the rainfall technique for the experiment is 87 %.

(a) (b) (c) (d)

Fig. 3 Photographs showing failure pattern at (a) unreinforced blast furnace slag and reinforced blast furnace slag for aspect ratio 1 with (b) mix ratio 1%, (c) mix ratio 2% and (d) mix ratio 3%.

Test procedure

A standard triaxial frame with a triaxial cell to accommodate the blast furnace slag sample of diameter 38 mm and 76 mm height was used to conduct experiments. For the reinforced samples care was taken that the dry mix of plastic strips and blast furnace slag is uniform. Proper care is taken to ensure that the while pouring the sample through the funnel, the plastic strips should not get accumulated at the opening of funnel and should be poured at the uniform rate. The height of fall i.e. 15 cm was kept constant throughout the experiments. Un-consolidate undrained triaxial tests were conducted as per Indian Standard IS 2720 (part 11):1993 with a constant strain rate of 1.25 mm min^{-1}. A load cell and Linear Variable Differential Transducer (LVDT) were used to measure the deviator load and vertical displacement respectively.Load cell and LVDT were connected to a digital screen. Both load cell and LVDT are calibrated before use. All the tests were conducted for maximum axial strain of 15%.

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Results and discussion

Series of un-consolidated Un-Drained (UU) triaxial tests were performed on reinforced blast furnace slag in dry conditions with different aspect ratios, different percentage of plastic strip apart from unreinforced sample. During the triaxial tests performed, the deviator load was applied on reinforced and unreinforced blast furnace slag. The failure patterns were observed for both unreinforced and reinforced specimen and are shown in Fig. 2 and Fig. 3. For the unreinforced blast furnace slag, the bulging is more predominant. Also more distortion in the shape of the specimen is observed. But for the reinforced samples, the bulging reduces with the reduction in distortion of the shape is also reduced.

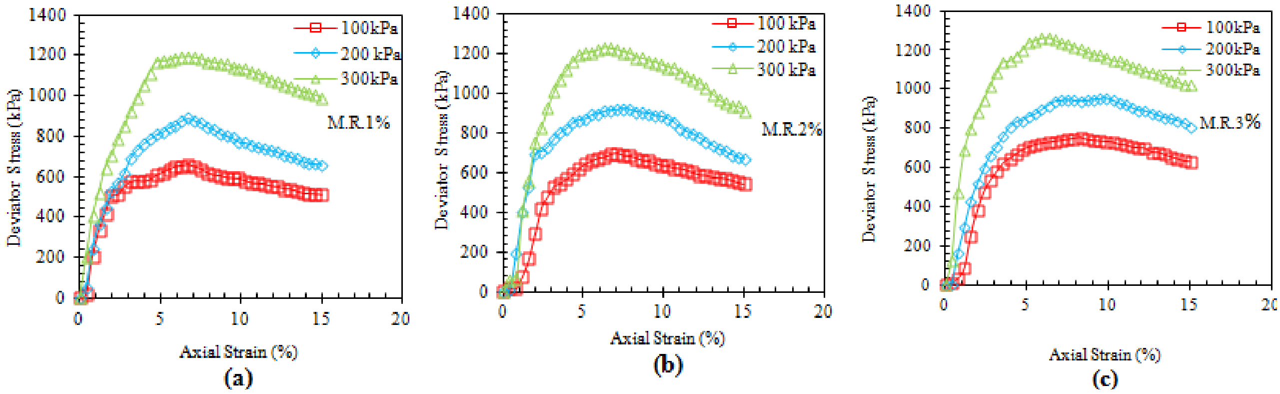

Fig. 4 Relationship between deviator stress and axial strain of reinforced blast furnace slag with aspect ratio 1 and mix ratios (a) 1%, (b) 2% and (c) 3%

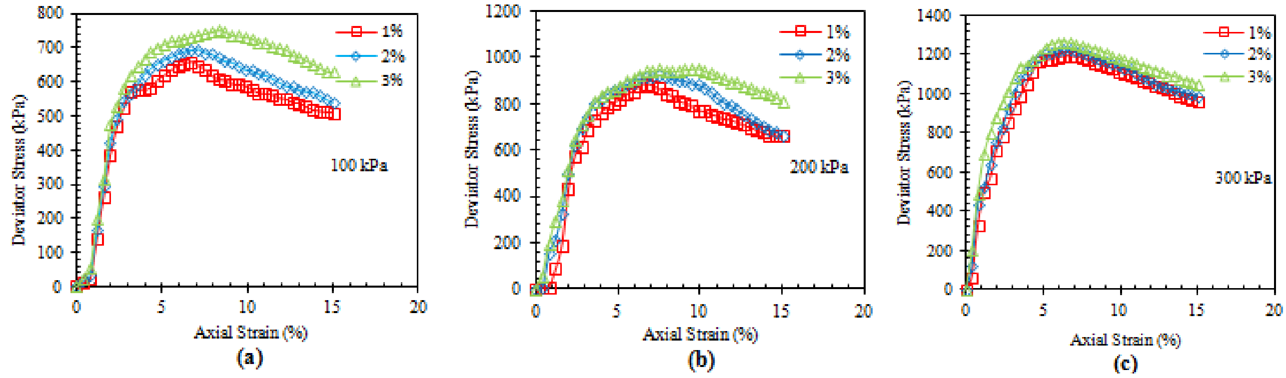

Fig. 5 Relationship between deviator stress and axial strain of reinforced blast furnace slag for aspect ratio 1 for cell pressure (a) 100 kPa, (b) 200 kPa and (c) 300 kPa

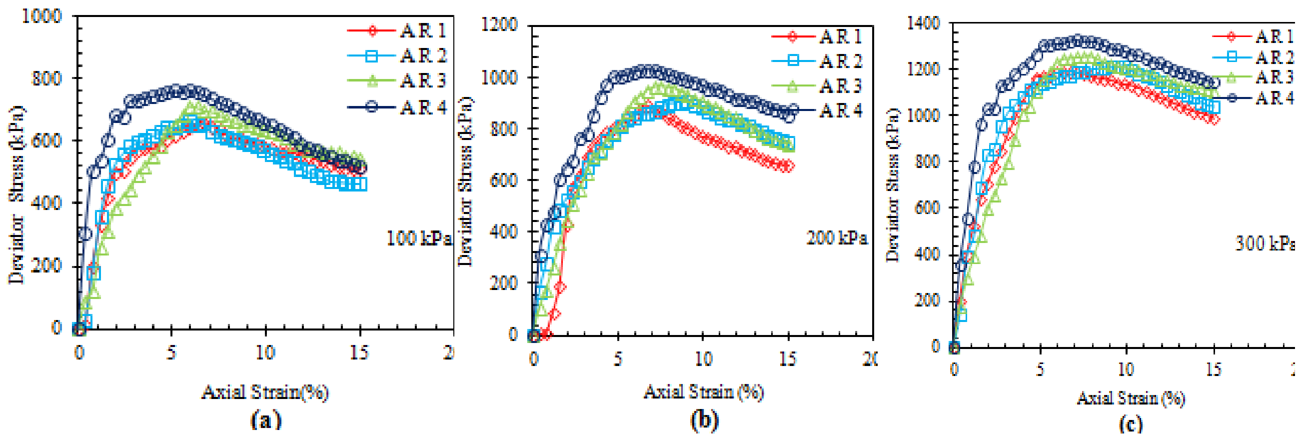

Fig. 6 Relationship between deviator stress and axial strain of blast furnace slag for mix ratio 1% and cell pressure (a) 100 kPa, (b) 200 kPa and (c) 300 kPa.

This may be due to the strengthening effect of the plastic strips reinforcement, through which the specimen achieved greater stability than the unreinforced one.

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Stress-strain behaviour

For the triaxial test, the deviator load is noted for each increment of axial deformation of blast furnace slag sample. The stress-strain curves were plotted and were classified on the basis of effects of mix ratios and aspects ratios of reinforcement. It has been observed that greater values of deviator stresses are recorded for all reinforced cases than unreinforced cases. The peak deviator stress is increased with increasing aspects ratios and mix ratios of plastic strips reinforcement.

It has been observed that the initial slope of the stress-strain diagram becomes steeper as the aspect ratios or mix ratio of reinforcement is increased. For all the reinforced cases of blast furnace slag samples, the deviator stress in increased quickly starting from very low strains and after reaching the peak deviator stress, the deviator stress is slightly decreased. AR 4 shows the higher values of deviator stress with mix ratio 3%, in comparison with other combination of aspect ratio and mix ratio. Fig. 4 shows the effect of mix ratios on the stress-strain curves. The similar pattern is obtained for other aspect ratios i.e. for AR 2, AR 3 and AR 4 with mix ratios. Stress straincurves were obtained for reinforced blast furnace slag for aspect ratio 1 with varying cell pressure i.e. 100 kPa, 200 kPa and 300 kPa shown in Fig. 5.

Shear strength parameters

Shear strength parameters cohesion (unreinforced), adhesion(for all reinforced samples), angle of shearing resistance (unreinforced) and friction angle (for all reinforced samples) are determined by plotting *p-q* diagrams. Fig. show the *p-q* diagrams for (a) unreinforced and (b),(c),(d) and (e) reinforced specimens. It is observed that for any aspect ratio, the cohesion is found to be increasing with increase in mix ratios and friction angle for any aspect ratio reduces with increase in mix ratios shown in Table II. The reinforced cohesion is found to be reducing, with increase in aspect ratio for any mix ratios. Whereas, the value of reinforced friction angle is increasing with increase in aspect ratios.

Deviator stress variation along with axial strain variation

The deviator stress σ_d varied from unreinforced to reinforced specimen.The test was carried out for cell pressure of 100 kPa, 200 kPa and 300 kPa. The deviator stress increases for reinforced specimens compared to unreinforced specimen. It is found that, the value of deviator stresses varied with aspect ratios and mix ratios. For any particular aspect ratios, with increase in mix ratios, the deviator stress is found to be increasing. Also, for a mix ratios selected, the value of deviator stress was increasing with increase in aspect ratios. The values of peak deviator stress corresponding to the axial stress for all selected aspect ratios and mix ratios are given in Table III.

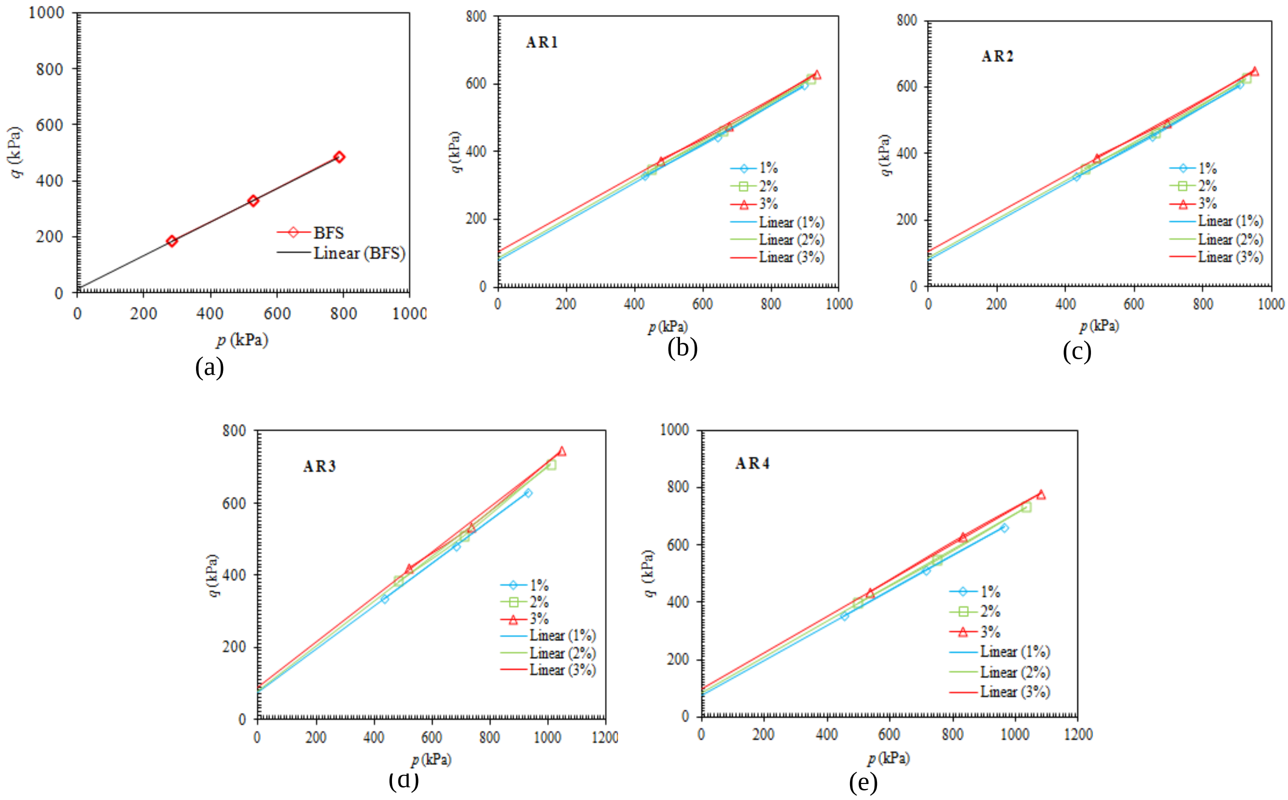

Fig. 7 *p-q* diagrams for a) unreinforced blast furnace slag and reinforced blast furnace slag with different aspect ratios (b) AR 1, (c) AR 2, (d) AR 3 and (e) AR4.

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Table II Shear strength parameters of blast furnace slag for both unreinforced and reinforced condition

Aspect Ratios	**Mix Ratios**	**Reinforced Cohesion kPa (C_r)**	**Reinforced Friction (ϕ_r)**
Unreinforced	-	-	32.997
A R 1	1%	80	30.133
	2%	90	29.769
	3%	106	29.558
A R 2	1%	79	30. 54
	2%	86	30.347
	3%	105	30.199
A R 3	1%	78	31.793
	2%	84	31. 3167
	3%	103	31.31
A R 4	1%	77	32. 4016
	2%	82	32.3377
	3%	100	31.9167

Table III Peak deviator stresses and corresponding axial strain for different aspect ratios and mix ratio of plastic strip for cell pressure 100 kPa, 200 kPa and

Aspect Ratios	Mix Ratios	100 kPa	200 kPa	300 kPa
Unreinforced		572.38(5.92%)	649.75(5.5%)	853.23(5.1%)
AR 1	1%	658.06(6.71%)	888.38(6.71%)	1192.73(6.71%)
	2%	696.23(7.10%)	921.64(7.50%)	1230.83(6.31%)
	3%	752.05(8.29%)	953.68(9.80%)	1263.87(6.71%)
AR 2	1%	658.06(6.71%)	905.91(9.07%)	1215.94(9.86%)
	2%	693.27(7.50%)	925.95(8.68%)	1253.41(8.28%)
	3%	779.65(7.89%)	1015.68(7.10%)	1302.36(7.21%)
AR 3	1%	713.40(5.92%)	962.42(7.50%)	1258.81(7.89%)
	2%	717.74(7.50%)	1019.52(7.50%)	1415.14(8.28%)
	3%	830.80(6.71%)	1086.69(5.92%)	1488.86(6.71%)
AR 4	1%	763.17(5.92%)	1028.22(6.71%)	1326.93(7.10%)
	2%	786.33(7.10%)	1098.65(6.31%)	1466.18(7.10%)
	3%	871.93(6.71%)	1159.83(6.71%)	1562.89(6.71%)

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CONCLUSION

An experimental study was conducted to examine the behaviour of plastic strips reinforced blast furnace slag for effective stabilization of blast furnace slag in geotechnical applications and also to make use of wasted and locally available plastic water bottles. A series of un-consolidated undrained triaxial tests were conducted on discrete reinforcement of plastic strips reinforced blast furnace slag samples with different aspects ratios and mix ratios.

The followings are the conclusions from the study:

1. For unreinforced BFS the bulging of specimen is more than that of the reinforced specimen. Also the distortion in shape of specimen is more in the unreinforced specimen than in reinforced specimen.
2. The bulging and the distortion of the specimen are found to be less as the aspect ratio increases with increasing mix ratios of the sample.
3. All the peak deviator stresses are obtained for an axial strain of 5-10%.
4. For reinforced blast furnace specimen, the deviator stresses and corresponding axial strains are found to be increasing with increase in aspect ratios and mix ratios of plastic strips and it is also observed that these values increases with increasing cell pressure values.
5. The reinforced cohesion value is found to be increasing for increasing mix ratios for particular aspect ratio. Whereas the value of reinforced cohesion is decreased as the aspect ratios of the plastic strips increased.
6. The reinforced friction angle is found to be lesser than the unreinforced blast furnace slag specimen.
7. The reinforced friction angle is increased for any mix ratio and increasing aspect ratios. Whereas, the value of frictional angle is reduced with increasing mix ratios for particular aspect ratio.

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