Direct shear behaviour of copper slag-geogrid interfaces

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ABSTRACT: Environmental pressure, high cost and shortage of natural aggregates creates the situation, to investigate the similar type of materials for geotechnical application. Limited use of copper slag has created huge heap of waste dump and large dump of slags not only requires plenty of land, but also wastes resources and can potentially have an impact on the environment. In this experimental study, large direct shear tests were conducted to obtaining the coefficient of interaction of two types of geogrid with copper slag and sand. A large size shear box of length 300 mm, width 300 mm and height 200 mm is used. The shear strength parameters of copper slag and sand were tested in large direct shear apparatus with and without geogrid. The performance of copper slag has compared to the sand. Biaxial geogrid made of polypropylene and triaxial geogrid made of bamboo strips were used. Based on the test results, the coefficient of interaction varies from 0.81 to 0.90 for polypropylene biaxial geogrid and 0.67 to 0.81 for bamboo triaxial geogrid. The unreinforced and geogrid reinforced copper slag was found to meet the shear strength criteria required for construction material in geotechnical applications.

Keywords: Large direct shear test, Geogrid, Copper slag, Sand, Bamboo, Coefficient of interaction

1 INTRODUCTION

Sand is a superior construction or backfill material used in various civil engineering projects, such as foundation, embankment, and retaining wall. The uncontrolled and excessive usage of natural aggregate materials in such applications has resulted in the construction industry in many countries facing increasing shortages of natural materials. Due to rapid industrialisation, an enormous amount of waste materials are being generated, which imposes significant pressure on landfill facilities and the environment. Copper slag is an industrial by-product material generated from the manufacturing process of copper. The annual production of copper slag has been approximately 35 million ton in the world (Lye et al., 2015).To the production of one-ton copper approximately 2.2 tons of copper slag generated (Gorai et al., 2003). In India, an estimated 1.63 million tons of copper slag generated by copper producer's viz., Birla copper Ltd., Dahej, Gujarat and Sterlite industries, Tuticorin, Tamil Nadu Ltd. (Prasad and Ramana, 2016). Das et al. (1983) performed tests on copper slag for its geotechnical characteristics and concluded that this material has similar properties as the medium sand. Several studies have been done on the cohesive and cohesionless soils with various types of reinforcement (Cazzuffi et al. 1993, Izgin et al. 1998, Palmeira et al. 2009, Anubhav and Basudhar 2010, Liu et al. 2010, Sayeed et al. 2014). However, no experimental studies have been done on interface characteristics of geogrid and copper slag. The main aim of the present study is to evaluate the feasibility of copper slag with the geogrid material. This paper presents the experimental study on interaction behaviour of biaxial geogrid (commercial) and triaxial bamboo geogrid (natural) with copper slag and sand.

2 MATERIALS

2.1 *Granular materials*

In this current study, the copper slag (CS), produced at Birla Hindalco Industries Limited, Dahej, Gujrat was used as fine aggregate and river sand used as reference material. According to the Indian Standard Soil Classification System, this sand and copper slag are classified as SP (poorly-graded sand).The grain size distribution curve is shown in Figure 1. Specific gravity, grain-size characteristics are presented in Table 1. Due to its granular nature, liquid limit and plastic limit could not be obtained for copper slag. The maximum and minimum dry densities of copper slag were calculated by the relative density test as per (IS 2720 part 14 2006).

Table 1. Physical properties of materials.

Properties	Materials	
	Copper slag	Sand
Specific gravity	3.62	2.64
Mean particle size, D_{50}(mm)	0.93	0.92
Effective size, D_{10}(mm)	0.45	0.65
Coefficient of uniformity,(C_u)	2.67	1.51
Coefficient of curvature,(C_c)	0.93	0.96
Soil classification (Indian standard)	SP	SP
Maximum unit weight,(kN/m^3)	21.68	15.30
Minimum unit weight,(kN/m^3)	19.03	13.24

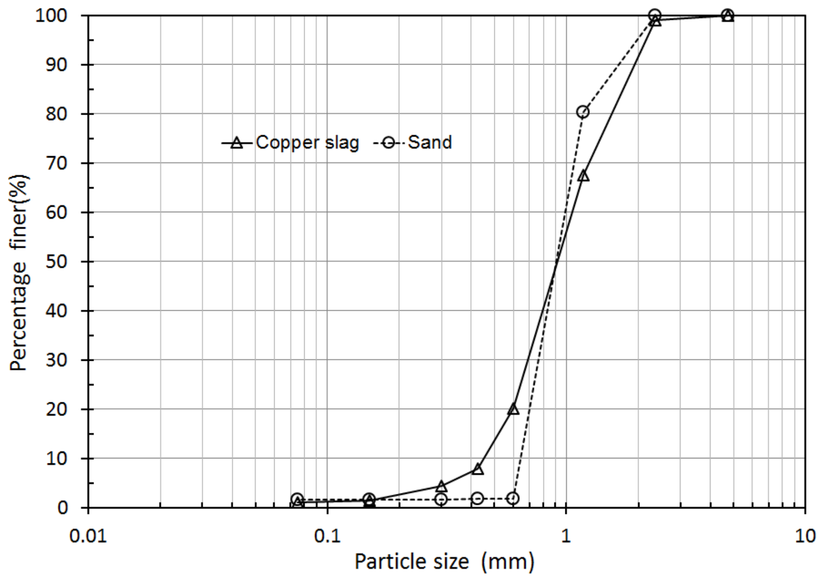


Figure 1. Grain size distribution curve for sand and copper slag

2.2 *Reinforcement*

Commercially available biaxial geogrid made of polypropylene was used in the experiment. The locally available bamboo strips were used in the form of triaxial grids (hexagonal aperture).The bamboo grids mattresses were made by strips of 3 mm wide and 1 mm thick to form a grid mattress, with an aperture size of 10 mm x 10 mm.The bamboo strips were immersed in the solution of borax and boric acid, for seven days. Borax and boric acid used to enhance its natural durability and to protect it from insects. The bamboo strips were dried in sunlight before use. The bamboo grids mattress were prepared manually.

Figure 3 shows the load-strain curve of biaxial and triaxial geogrid obtained from tensile strength test according to ASTM D4595 (2011).The physical and mechanical properties of biaxial and triaxial geogrid are presented in Table 2.

Table 2. Properties of reinforcement.

Properties	Reinforcement	
	Biaxial geogrid(PP)	Triaxial geogrid(Bamboo)
Aperture shape	Square	Hexagonal
Aperture size	36 mm × 36 mm	10 mm × 10 mm
Tensile strength (kN/m)	29	19

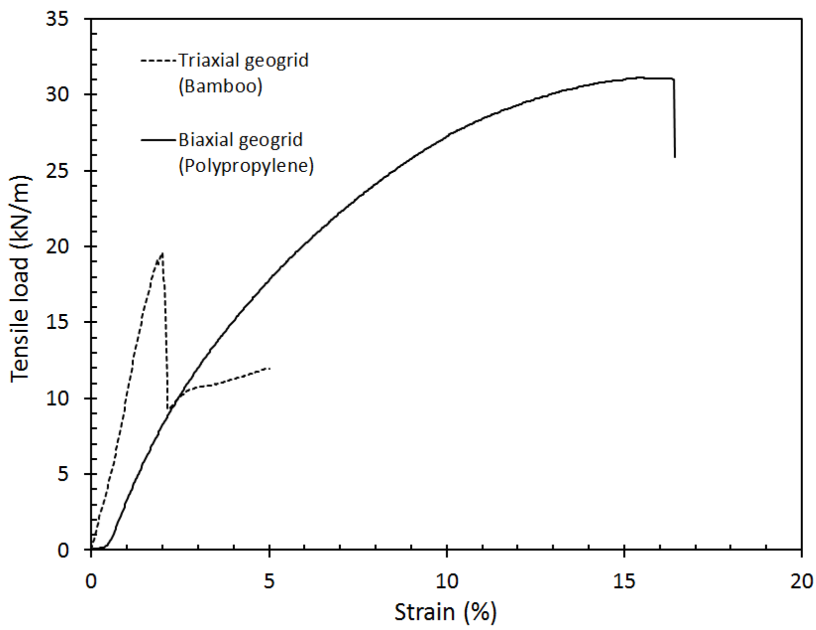
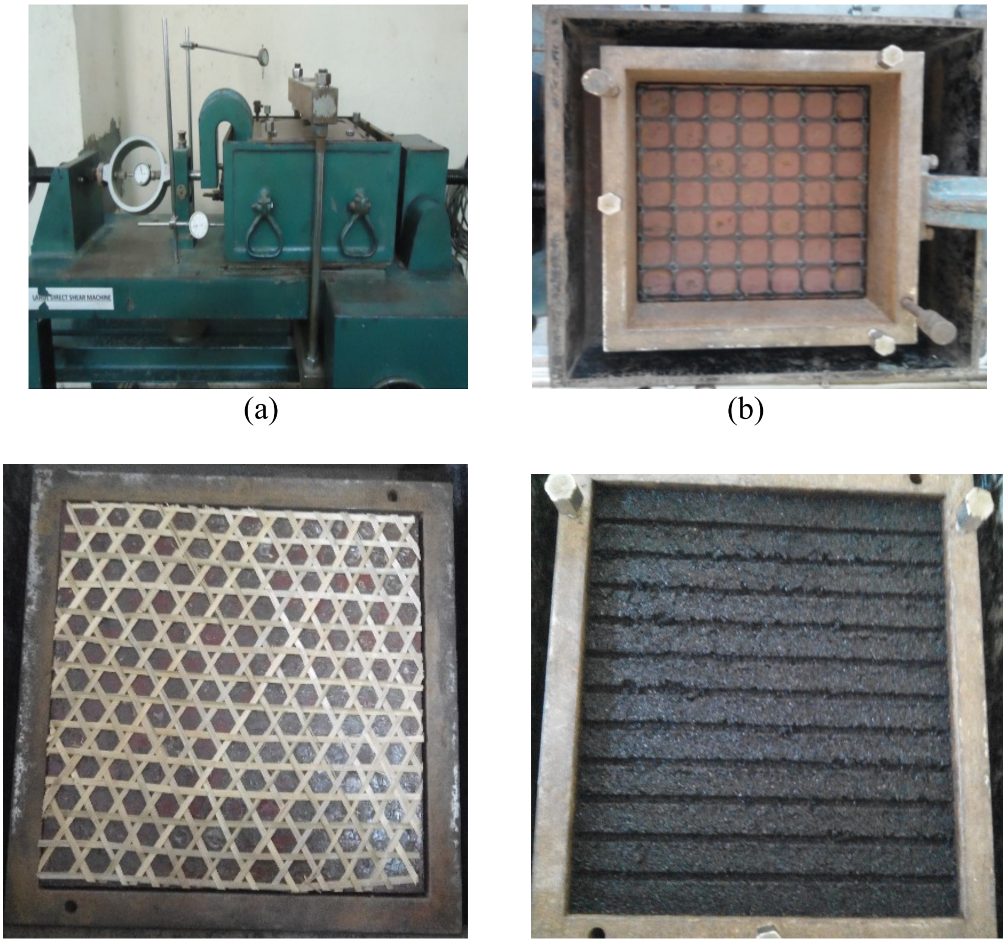


Figure 2. Load-strain curve of biaxial and triaxial geogrid in tension test

3 LABORATORY TESTING PROGRAM

The large-size direct shear test was initially conducted to measuring the shear strength parameters of sand and copper slag. Subsequently, the interface shear strength tests for geogrid and sand or copper slag were conducted for measuring the characteristics of shear resistance that develops between the copper slag or sand and the geogrid.

A direct shear apparatus of a large box of size equal to 300 mm × 300 mm was used in the present study, for investigation the interface shear properties of sand and copper slag alone and same materials with geogrid. It consists of two hollow boxes of size equal to 300 mm × 300 mm × 115 mm namely lower half box and upper half box. The lower part of box of large direct shear setup was fixed with a rigid dummy wooden block of dimensions 295 mm × 295 mm × 100 mm which was used for fixing geogrid on the top surface of the wooden block. The sand and copper slag were used in the experiment on air-dried condition. The dry unit weights of compacted sand and copper slags were 14.10 kN/m^3 and 20.81 kN/m^3. The initially large direct shear test was performed by filling upper and lower parts of the shear box at a relative density of 70%.



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

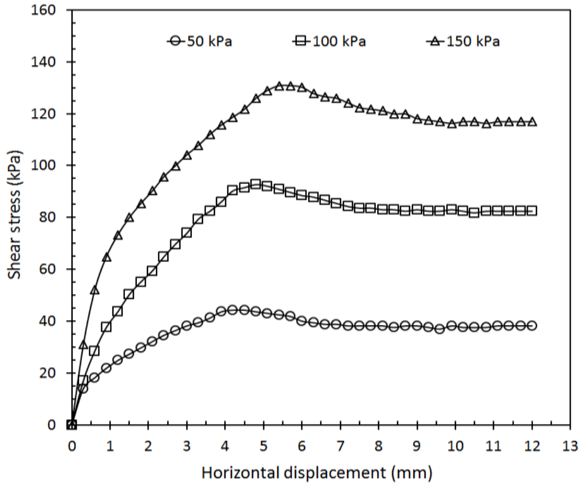
Figure 3.(a) Large size shear box (b) Placing of geogrid (c) Triaxial geogrid (d) Copper slag

For obtaining the interface shear strength properties of sand/geogrid and copper slag/geogrid, the large-size direct shear tests were conducted according to [14]. The geogrid fitted on the top surface of dummy wooden block which was placed in the lower part of the shear box shown in the figure. The upper part was placed properly on lower half by inserting pins and filled with sand. For achieving target density, sand was placed in layers of 25 mm thickness and tamped with the square metal plate. The constant normal stresses of 50 kPa, 100 kPa, and 150 kPa were applied on the sample. The test was performed at a displacement rate of 1 mm/min for all tests. The same procedure was adopted for copper slag with geogrid.

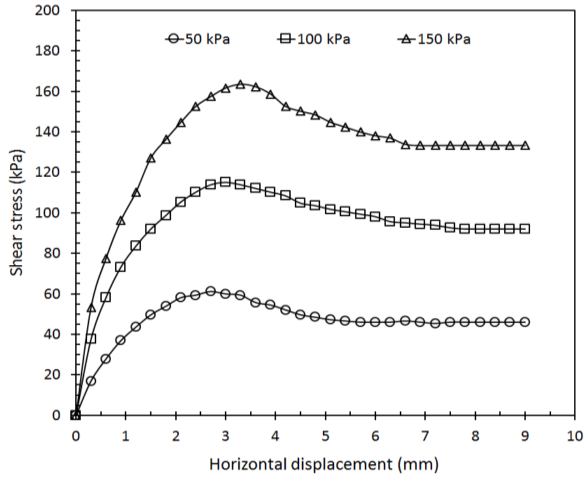
3 RESULTS AND DISCUSSION

3.1 *Shear stress-displacement relationship*

Figure 4 shows the shear stress and horizontal displacement behaviour of sand at three different normal stress values. The peak shear stress values of sand were obtained in the range of 4 mm to 6 mm horizontal displacement, while residual shear stress values were found at horizontal displacement in the range 6 mm to 9 mm. The peak shear stress values of copper slag were obtained for horizontal displacement in the range 2 mm to 3 mm, while residual shear stress values were found at horizontal displacement in the range 5 mm to 7 mm.

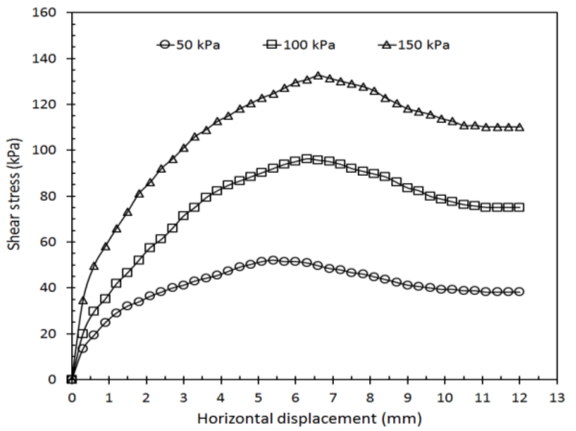


(a)

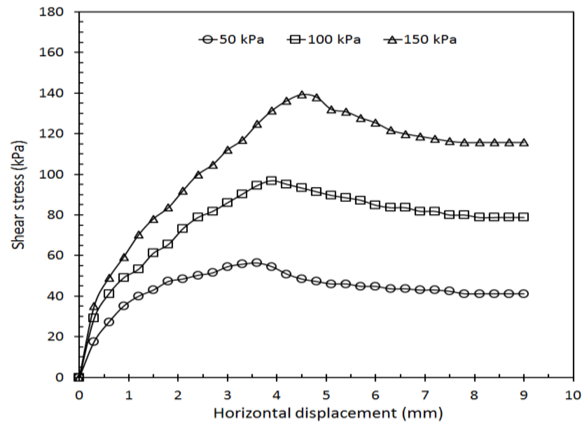


(b)

Figure 4. Variation of shear stress and horizontal displacement for (a) sand (b) copper slag

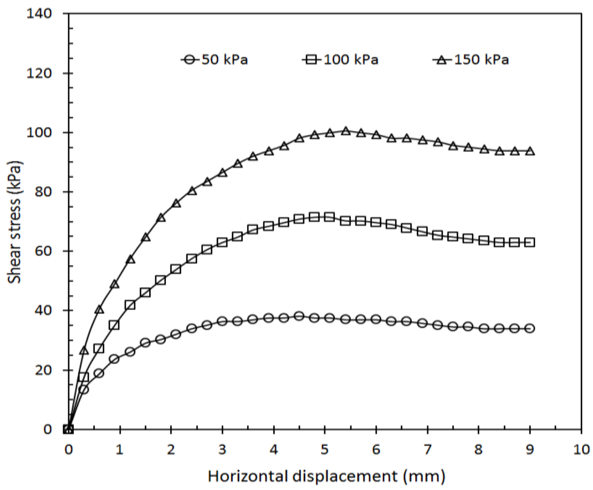


(a)

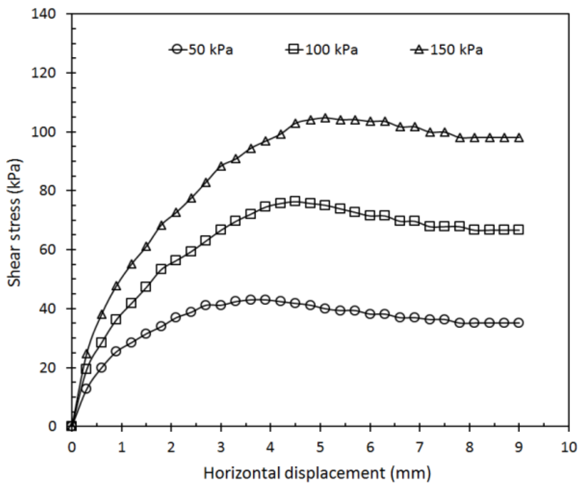


(b)

Figure 5. Variation of shear stress and horizontal displacement for (a) sand-biaxial geogrid (b) copper slag-biaxial geogrid



(a)

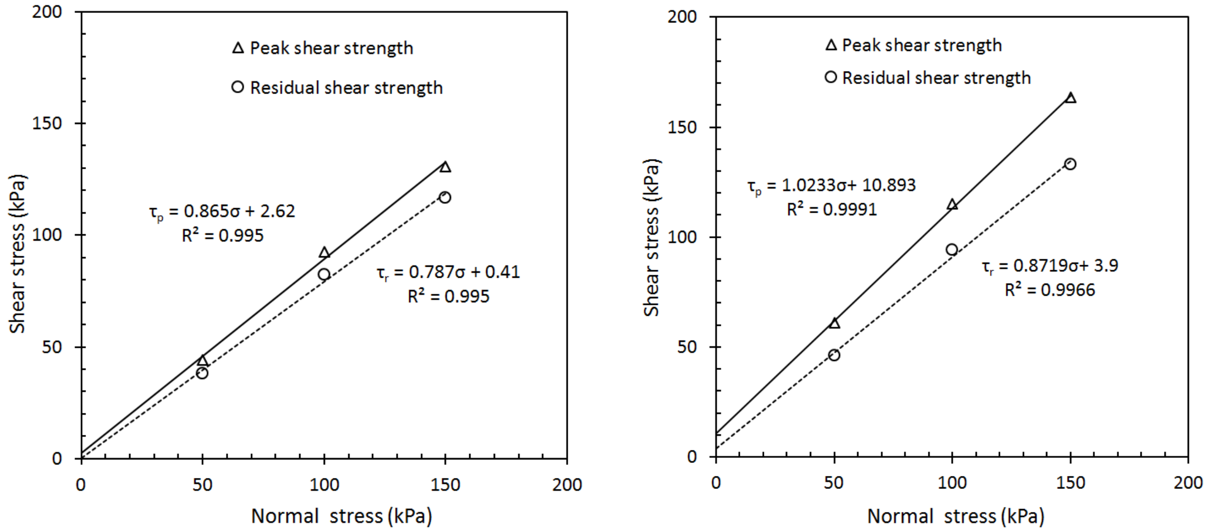


(b)

Figure 6. Variation of shear stress and horizontal displacement for (a) sand-triaxial geogrid (b) copper slag-triaxial geogrid

Figure 7 presents shear strength envelopes of sand and copper slag without geogrid in terms of the peak and residual states for different normal stress values. Based on the Mohr-Coulomb failure criterion, the parameters of shear strength (cohesion c and angle of internal friction ø) were found for sand to be 2.62 kPa and 40.88°, and 0.41 kPa and 38.20° at peak and residual states respectively.

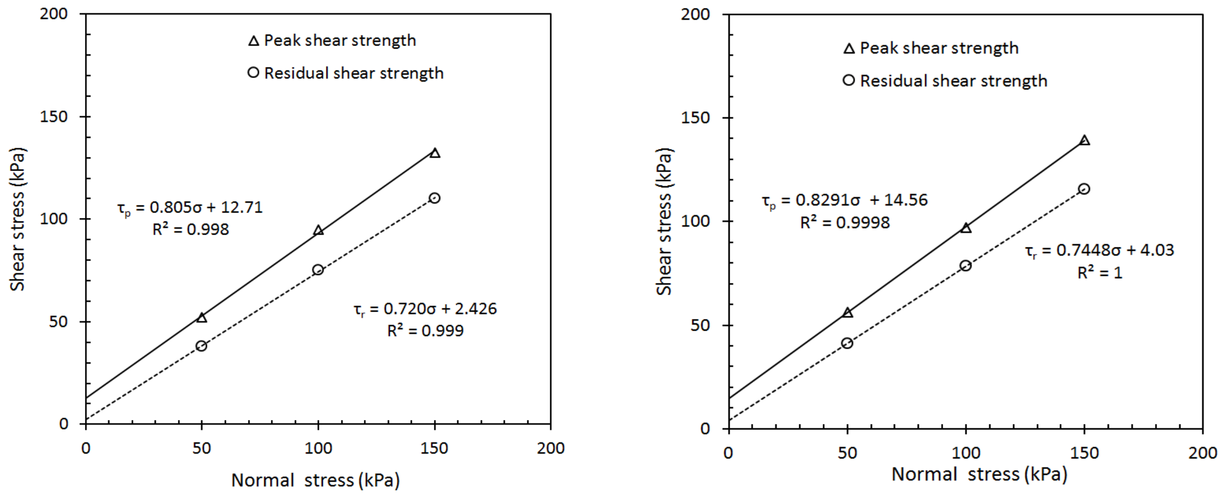
Similarly, for copper slag, the shear strength parameters were found to be 10.89 kPa and 45.66°, and 3.9 kPa and 41.05° at peak and residual states respectively.



(a) (b)

Figure 7. Shear strength envelopes for (a) sand and (b) copper slag at peak and residual states

Figure 8 presents shear strength envelopes of sand and copper slag with biaxial geogrid in terms of the peak and residual states for different normal stress values. Based on the Mohr-Coulomb failure criterion, the parameters of shear strength (adhesion c_a and interface friction angle δ) were found for sand to be 12.7 kPa and 39°, and 2.42 kPa and 36° at peak and residual states respectively. Similarly, for copper slag, the shear strength parameters were found to be 14.56 kPa and 39°, and 4.03 kPa and 37° at peak and residual states respectively.



(a) (b)

Figure 8. Shear strength envelopes for (a) sand-biaxial geogrid (b) copper slag-biaxial geogrid at peak and residual states

Figure 9 presents shear strength envelopes of sand and copper slag with triaxial bamboo geogrid in terms of the peak and residual states for different normal stress values. Based on the Mohr-Coulomb failure criterion, the parameters of shear strength (adhesion c_a and interface friction angle δ) were found for sand to be 7.67 kPa and 32°, and 3.64 kPa and 31° at peak and residual states respectively. Similarly, for copper slag, the shear strength parameters were found to be 12.92 kPa and 32°, and 3.63 kPa and 32° at peak and residual states respectively.

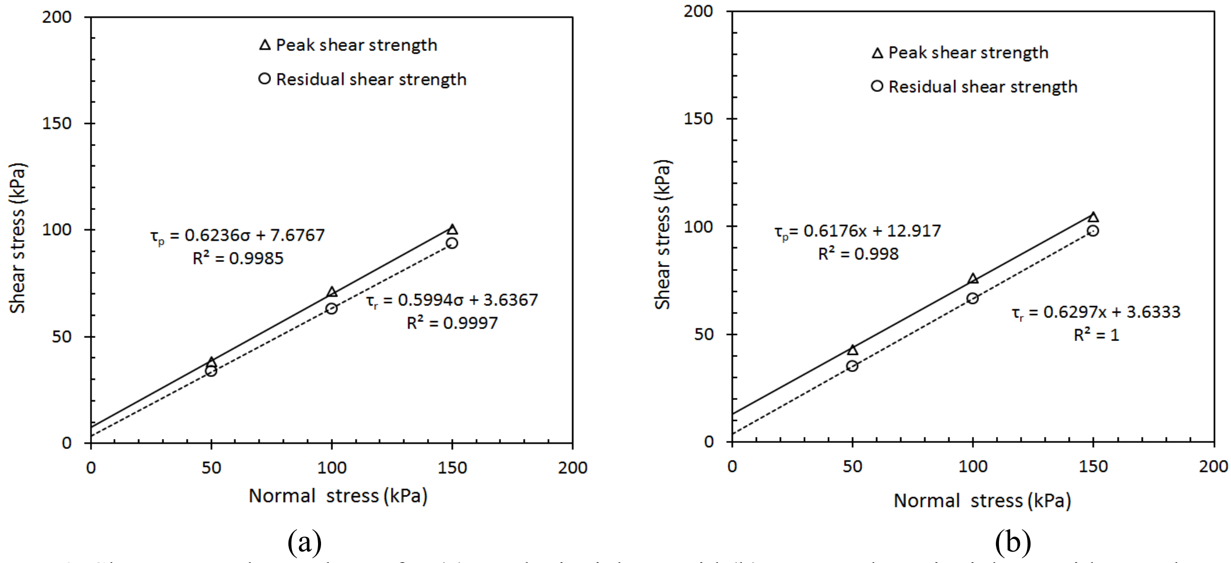


Figure 9. Shear strength envelopes for (a) sand-triaxial geogrid (b) copper slag-triaxial geogrid at peak and residual states

3.2 *Coefficient of Interface shear strength*

The interface shear strength coefficient is defined as the ratio of the shear strength in a soil-geosynthetics direct shear test, $\tau_{soil/geo}$, to the shear strength in a direct shear test on soil, τ_{soil}, under same normal stress

$$c_i = \frac{\tau_{soil/geo}}{\tau_{soil}} = \frac{c_a + \sigma \tan \delta}{c + \sigma \tan \emptyset} \quad (1)$$

The coefficient of interaction or interface shear strength coefficient of sand-geogrid and copper slag-geogrid were determined from the equation. Table 3 summarises the values of the interface shear strength coefficient of the interfaces for normal stresses of 50, 100 and 150 kPa.

Table 3. Coefficients of interaction for sand and copper slag geogrid interfaces.

Interface material	Coefficients of interaction	
	Peak state	Residual state
Sand-biaxial geogrid	0.90	0.98
Sand-triaxial geogrid	0.79	0.81
Copper slag-biaxial geogrid	0.81	0.85
Copper slag-triaxial geogrid	0.67	0.72

From the test results, it is found that the coefficient of interaction ranges from 0.79 to 0.98 for the sand-geogrid interface and 0.67 to 0.85 for copper slag-geogrid interface. (Cazzuffi et al., 1993) Presented coefficients of interaction values in the range of 0.83-1.04 for soil-geogrid interfaces, and (Liu et al., 2009 and Umashankar et al., 2015) reported values of interfaces shear strength coefficient ranging from 0.89-1.01 for different soil-geogrid interfaces. The coefficient of interaction for geogrid with copper slag and sand were obtained from this study have good agreement with the values available in the literature.

4 CONCLUSION

The grain size distribution, physical properties, and shear strength parameters of copper slag are found similar to medium sand and copper slag fulfil the criteria as a backfill material for reinforced soil structures as per FHWA-NH-00-0043 and BS 8006 specifications. The values of interaction coefficients for sand-geogrid were found more than that of copper slag. From the results of the large-size direct shear test with geogrid embedded in sand and copper slag shows that copper slag has a suitable material for using an alternative backfill material for reinforced soil structures. Triaxial geogrid made of bamboo gives good performance in terms of shear strength parameters. The interface strength of copper slag-bamboo geogrid is found to be equivalent as compared to the sand-bamboo geogrid interface.

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