

# Variations in the Interface shear strength of GCL with Manufactured Sand

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**Abstract.** In view of the problems of sand extraction and its harmful impact on the coastal erosion, research now focusses on viable alternatives. Manufactured sand (M-sand) has become an admissible alternative to be used in concrete instead of river sand. In countries like India, sand mining is illegal, considering the adverse effects it can cause to river basins. Replacement of river sand with M-sand as a suitable subgrade or capping material in landfills needs to be investigated. When Geosynthetic Clay Liners (GCL) are used on sloping grounds, interface friction between GCL and the base soil becomes important to ensure bonding and arrest slippage issues. While the interface shear characteristics of natural sand with GCLs are well established in literature, not many studies are reported on the interface characteristics of GCLs and M-sand. This study is an approach towards understanding the interface shear strength parameters of GCLs with manufactured sand and compare them against those of river sand under identical loading conditions. To avoid the effects of morphology, identical gradation of both the sands is used in the tests. This gradation is arithmetic average of grain sizes of both the sands, which is achieved by tweaking with the proportions of different sized grains. Chemical analysis of both the sands is carried out for comparison. A GCL with bentonite sandwiched between a woven geotextile on one side and non-woven geotextile on the other side is used in the tests. Interfacing surface is a nonwoven-geotextile in all the tests. Interface shear tests are carried out on River sand-GCL and M-sand-GCL interfaces to obtain interface friction angle of both these interfaces. The variations in the shear strength parameters are further analyzed under hydration conditions of the subgrade. Further, damage assessment of GCL surface due to interaction with these two different types of sands is carried out using Scanning Electron Microscopy and image analysis. Results from these studies provided clear directions towards the replacement of river sand with M-sand in landfills in terms of interface friction characteristics and the comparative surficial changes in GCLs with the indentation of sand particles, which can give confidence about sand replacement.

**Keywords:** Interface shear strength, Geosynthetic clay liners, Msand, Image analysis

## 1 Introduction

The use of geosynthetics in combination with geomaterials like soil, rock etc. has provided a highly competent structure in terms of strength, durability and perfor-

mance. They have given a solution to fast depleting resources in form of economical construction. The use of Geosynthetic Clay Liner (GCL) in place of compacted clay liners has been a widely accepted and practiced technique. The GCL can be defined as a prefabricated geocomposites, the juxtaposition of geosynthetic and natural soil, which offer high quality performance as hydraulic barriers. They are the vital components of the base liners and capping material of an engineered landfill. The assessment of the interface and internal shear strength is a prerequisite for the stability conditions that arise on slopes. The studies on interface of geosynthetics were done with shear tests and the assessment of the strength was with peak and residual values [1]. Relevant studies and insight have been provided on the interface strength between GCL and geomembrane, which form the interfacing surface in double liners [2]. However, the works to understand the influence of soil as base material when interfaced with GCL, have not been explored in detail. The studies have highlighted the effect of subgrade materials on internal erosion of GCL [3]. The relevance of bonding between the GCL and base material comes into picture during the stability analysis. The frictional characteristics is associated with the morphology of the interacting particles. From recent works, sand has been identified as an appropriate material for establishing the required frictional characteristics [4]. The identification and differentiation of particles based on shape and size parameters have been innovatively done with image analysis [5].

The present study is an attempt to replace the river sand with Msand as an interfacing material in the placement of GCL in liner and capping facilities. The interface shear strength characteristics is assessed with modified direct shear setup. The preliminary studies focus on the gradation and the chemical composition of the river sand and Msand. The quantification of the shape parameters of the interfacing particles and changes to the interfacing surface of GCL is assessed with Image analysis to provide an insight into the proposed replacement.

## **2 Material Characterization**

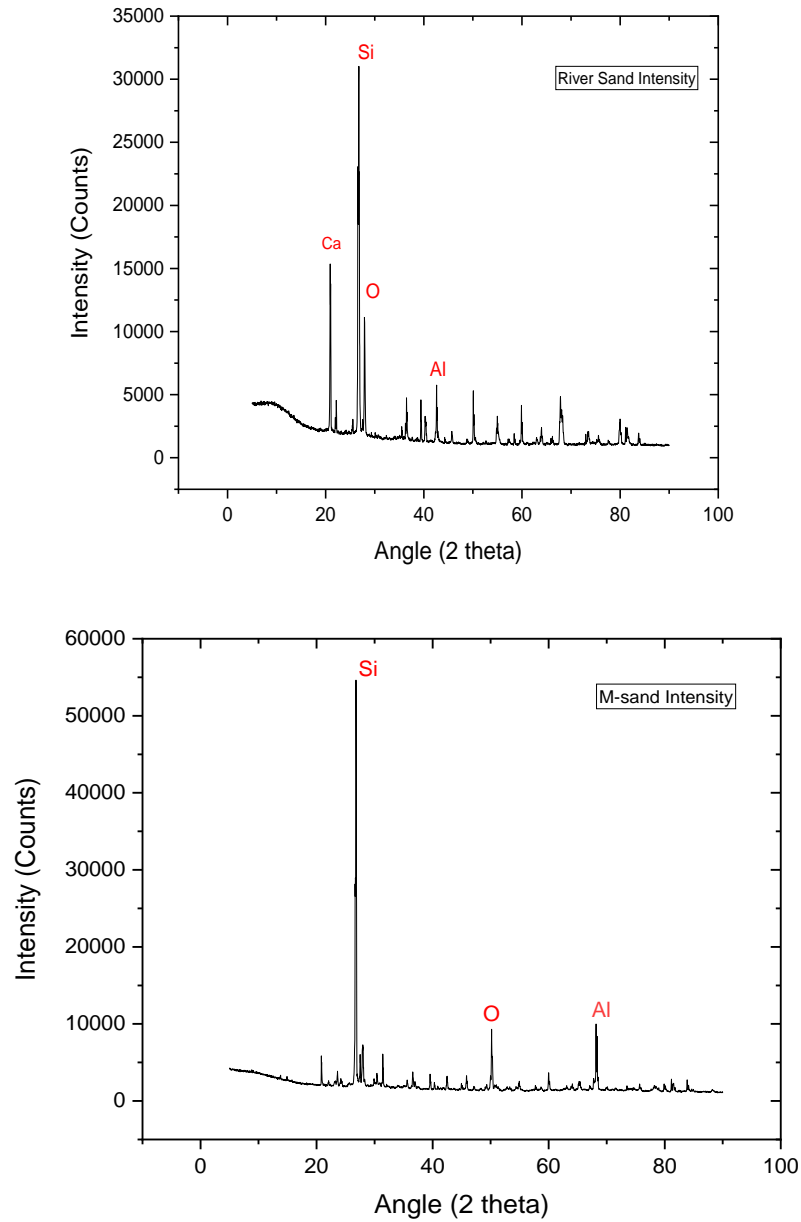
### **2.1 Geosynthetic Clay Liner**

The Geosynthetic Clay Liner (GCL) used in the study is bentonite encapsulated between non-woven and woven geotextile, needle punched together for maximum performance. It is a factory product with a commercial name Macline GCL W.

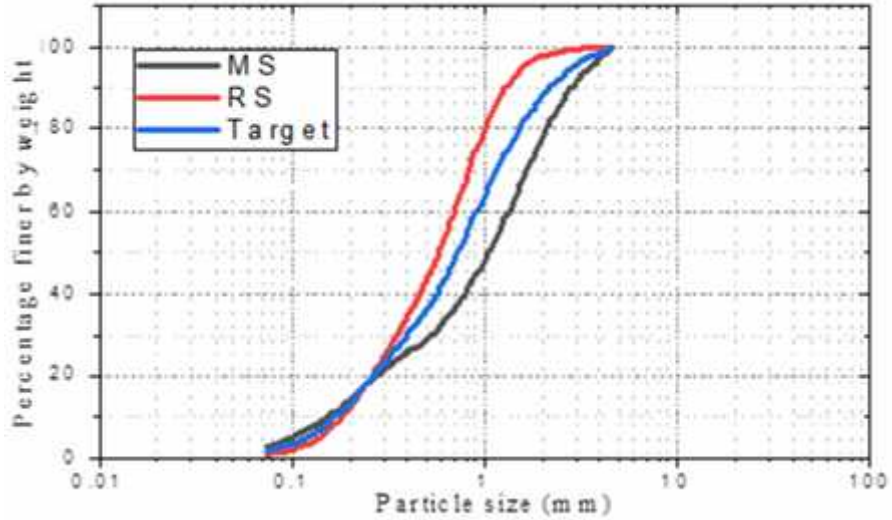
### **2.2 Base materials – River sand and Msand**

The preliminary studies were conducted to acquire the information on compositional aspect with XRD analysis. The plots showed chemical composition of silica, alumina and calcium oxides to be predominant in both river sand and Msand (Fig 1). The gradation plot categorized river sand as SP and Msand as SW based on IS classification (Fig 2). To perform the test in identical conditions and to minimize the effect of size of particles, the gradation was tweaked to the average gradation. The direct shear tests

performed for relative density of 80% gave the friction parameter for river sand and Msand as  $44.4^\circ$  and  $47^\circ$  respectively.



**Fig. 1.** The plots of XRD analysis for River sand(top) and Msand(bottom)



**Fig. 2.** The gradation plot for river sand and Msand and Target gradation

### 3 Experimental Setup

The GCL specimens were cut-out in required dimensions from the factory roll (Fig 3). The target gradation was sieved out from river sand and Msand for the tests. The first phase of testing was done under normal stresses of 30kPa, 60kPa and 100kPa for air-dried samples. The second phase of testing was done for moisture content of 6%, 12% and 25% of base material. The shearing rate for all the tests was 0.625mm/min.



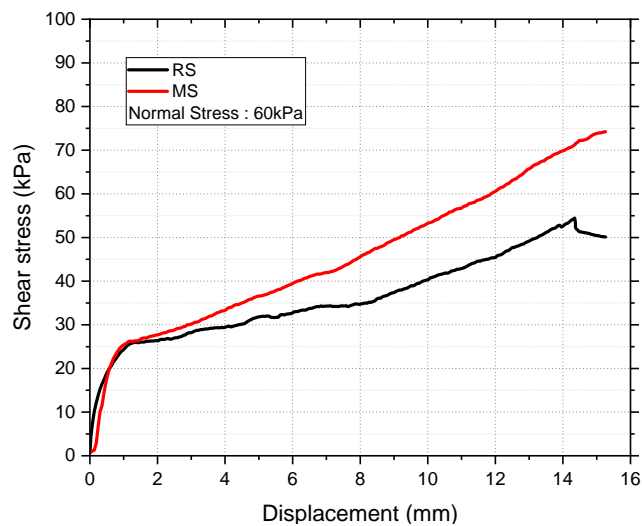
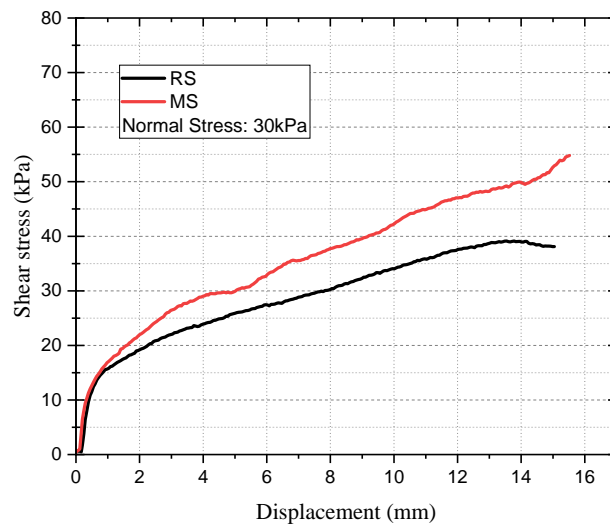
**Fig. 3.** The cut-out specimens of GCL

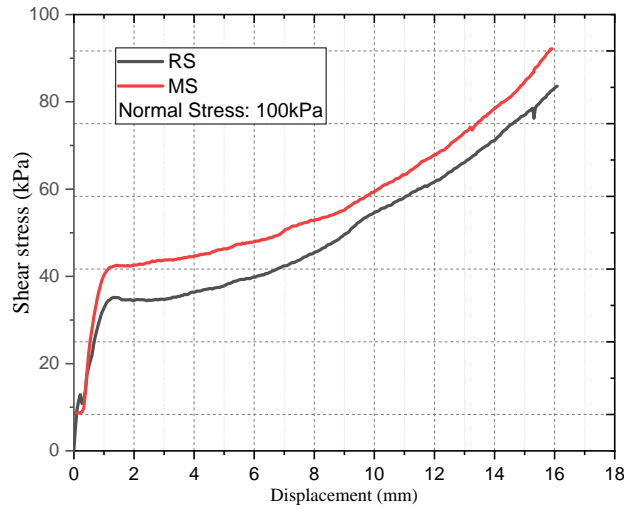
The test results were analyzed for the interface shear strength in terms of the cohesion and friction parameter. Further the variations in the interface shear stress under the hydration of GCL via suction of moisture was analyzed.

## 4 Results and Discussion

### 4.1 Interface shear stress with different base materials

The variations in the interface shear stress under normal stress of 30kPa, 60kPa and 100 kPa highlight a distinct increase in the interface shear strength when Msand is used as the interfacing material with GCL (Fig 4.1 (a)-(c)). The increase is significant beyond 2mm of horizontal displacement.





**Fig. 4.** The Shear stress v/s displacement plot for normal stress of 30,60 and 100kPa

The interface shear stress is assessed by the Mohr-Coulomb plot which can be given by the peak stress envelope as -

$$\tau(p) = a(p) + \sigma \tan \Phi(p)$$

Where,  $\tau(p)$  – shear stress at peak

$a(p)$  – adhesion factor of interface at peak

$\Phi(p)$  -- angle of friction at peak

The shear stress v/s normal stress plot gives the value of  $\Phi(p)$  as  $37^\circ$  and  $34^\circ$  for Msand and river sand respectively (Fig 5). The values of  $a(p)$  are 49 kPa and 35kPa for Msand and river sand respectively which is indicative of the better interlocking of the interfacing particles with the non-woven GCL.

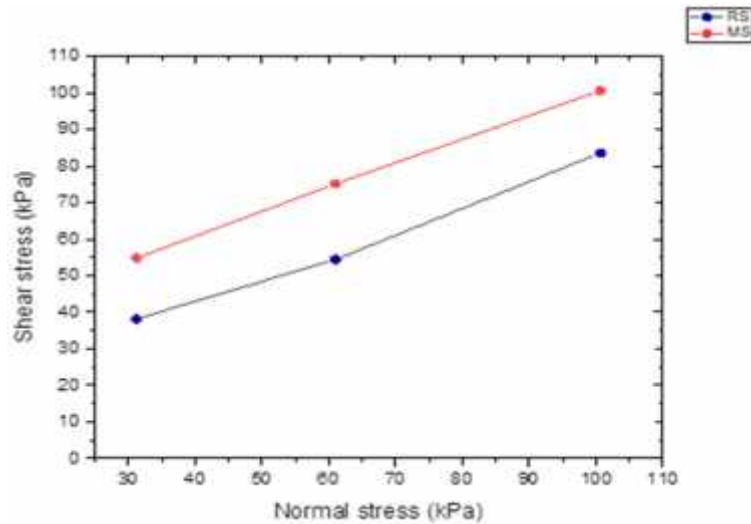
The comparative analysis of river sand and Msand as base material for GCL shows a significant increase in the interface angle of friction,  $\Phi(p)$ , for Msand. It shows a better interlocking of the Msand particles with the non-woven geotextile fibres leading to high adhesion values as well. This provides conclusive evidence to a better performance and stability being offered by the GCL-Msand interface.

## 4.2 Interface shear strength under hydration conditions

The hydration of GCL is a very important aspect in the strength assessment since the powdered bentonite encapsulated between the geotextiles exhibit swelling characteristics upon hydration. It significantly effects the structure and the strength of GCL.

The hydration of GCL can take place under the listed circumstances –

- Through punctured hole in the geomembrane which enables the hydration through leachate where the interface is GCL-Geomembrane.
- Through suction from the subgrade or cover materials.



**Fig. 5.** Shear stress v/s normal stress

The study conducted with changes in moisture conditions of the subgrade from 6%, 12% and 25% gives an understanding of the variations in the interface shear stress development for GCL-River sand and GCL-Msand interfaces.

The normal stress was maintained at 100.67kPa while the moisture conditions was varied for river sand and Msand. The plot shows a reduction in interface shear stress for both GCL-river sand and GCL-Msand interface (Fig 6). The reduction is attributed to the lubricating effect of water and the extruded bentonite at the interface which forms a slicken layer between the interfacing surfaces.

The free -swell conditions developed in GCL results in pressure being generated which results in pull out of the needle punched reinforcing fibres thus altering the shear stress characteristics (Lake and Rowe, 2000). The swell pressure developed in GCL for river sand and Msand have resulted in maximum reduction of shear strength between 0-12% moisture conditions (Fig 7). The pull-out of reinforcing fibres have resulted in entanglement that leads to more particles being trapped at the shearing surface of GCL (Fig 8).

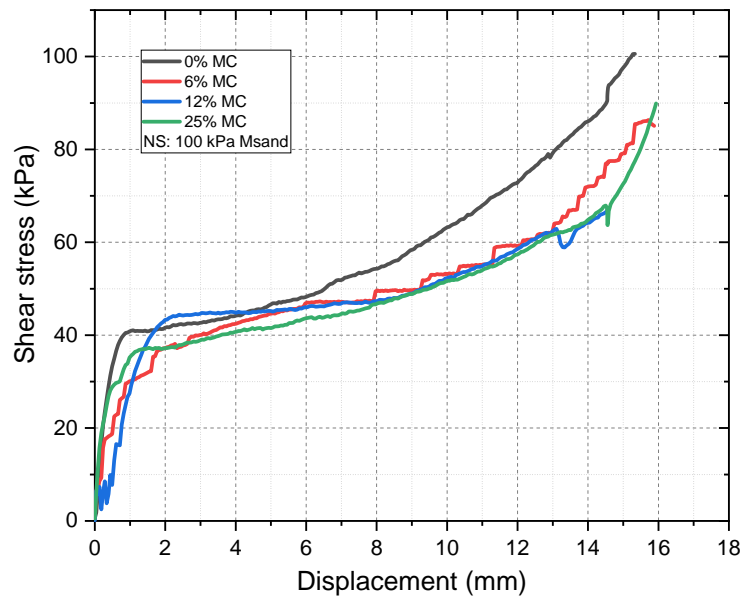
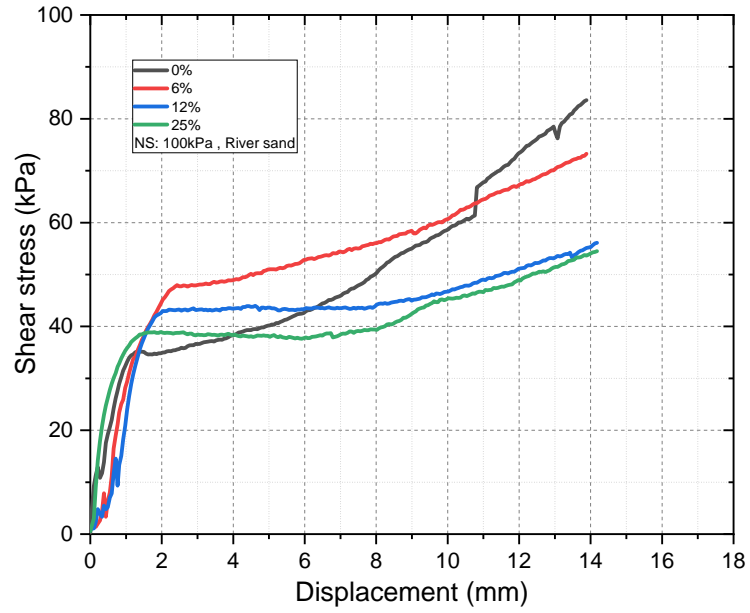


Fig. 6. Shear stress v/s displacement for tested moisture conditions of subgrade



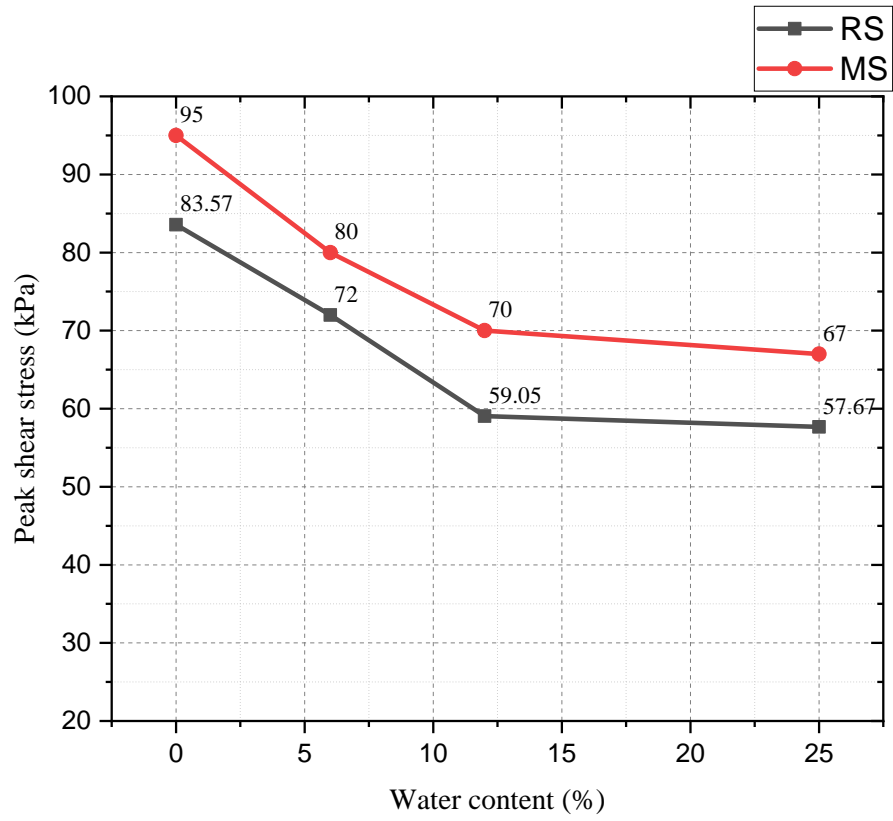
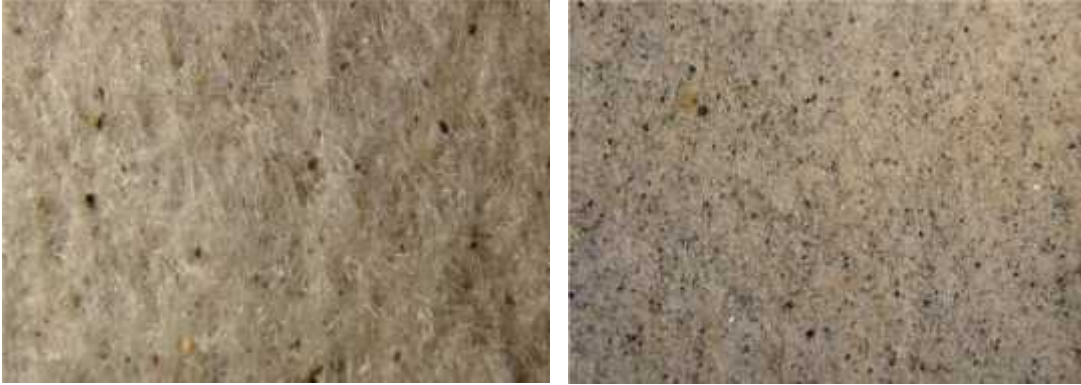


Fig. 7. The variation of shear stress with water content of subgrade.



Fig. 8.1 Sand- fibre adhesion in GCL-River sand interface tested dry (left) and tested with 25% water content (right)



**Fig. 8.2** Sand-fibre adhesion in GCL-Msand interface tested dry (left) and tested with 25% water content (right).

## 5 Image analysis

Image analysis is an extensively used technique for extraction of useful information based on analysis of digital images. In this study, it is employed for characterization of particles based on grey levels of digital and optical microscopic images. The shape characterization of the sand particles is done through optical microscopic images and the image analysis in MATLAB. Further, the assessment to the changes of the interfacing surface of GCL provides an insight into the variation of shear strength due to hydration conditions.

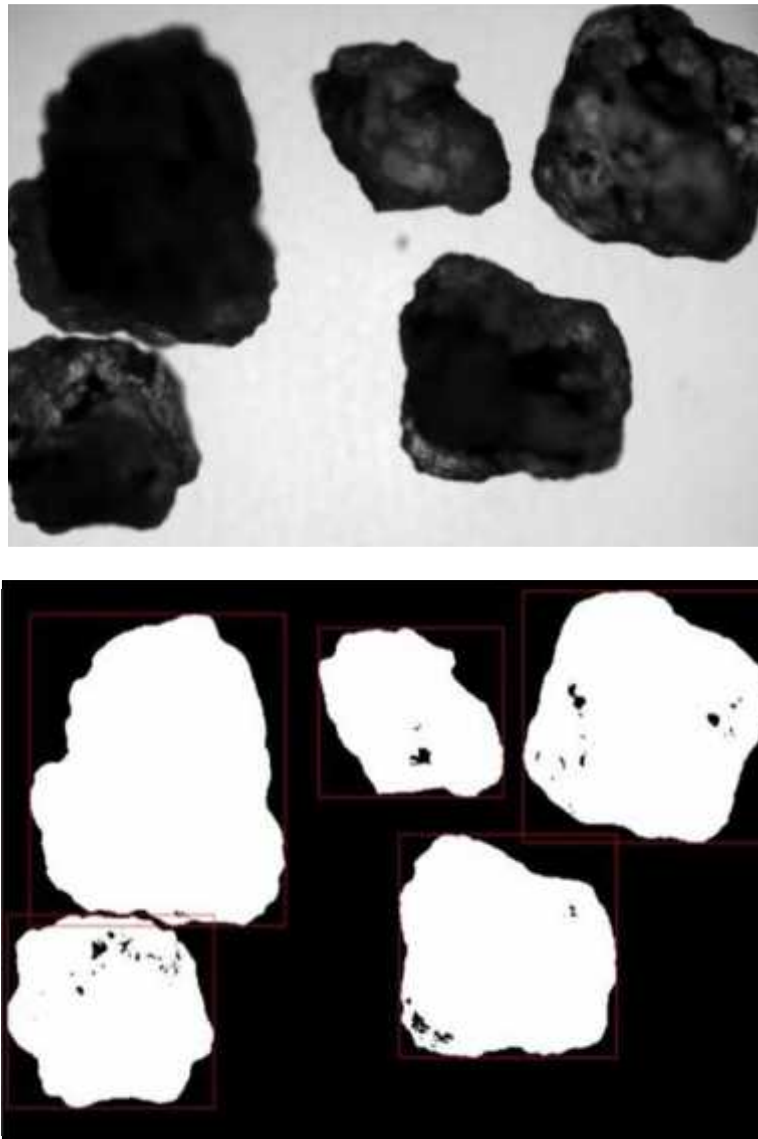
### 5.1 Shape characterization of sand particles

The influence of particle shape and size in the shear behavior of granular material have been recognized in many studies. In this study, the primary focus is on the effect of shape of interfacing particles as the effect of size is minimized by adopting target gradation for the tests. Convexity, Circularity, Aspect ratio are among the few descriptors of particle shape. An attempt to quantify the shape of river sand and Msand particles have been done based on image analysis for specific size ranges.

#### Image acquisition and thresholding

Images of sand particles were captured using Nikon eclipse 80i optical microscope and the O-Imaging Micropublisher imaging system to capture images at 20x magnifi-

cation. The captured images were converted to greyscale and thresholded and segmented using MATLAB (Fig 9).



**Fig. 9.** Greyscale image of particles (top) and segmented particles (bottom)

### Quantification of shape descriptors

The images were analyzed for convexity, circularity, aspect ratio and elongation to quantify the shape of particles and determine the differences between the river sand and Msand particles.

<b>Size -1.18mm</b>	Aspect ratio	Circularity	Convexity	Elongation
RS	0.8509	0.7192	0.9125	0.1491
MS	0.7145	0.7123	0.9077	0.2855
<b>Size – 0.6mm</b>				
RS	0.8420	0.8020	0.8927	0.158
MS	0.8166	0.7823	0.9075	0.183
<b>Size – 0.3mm</b>				
RS	0.8213	0.8910	0.9229	0.1787
MS	0.7439	0.7260	0.8791	0.2561

**Table 1.** Particle shape descriptors

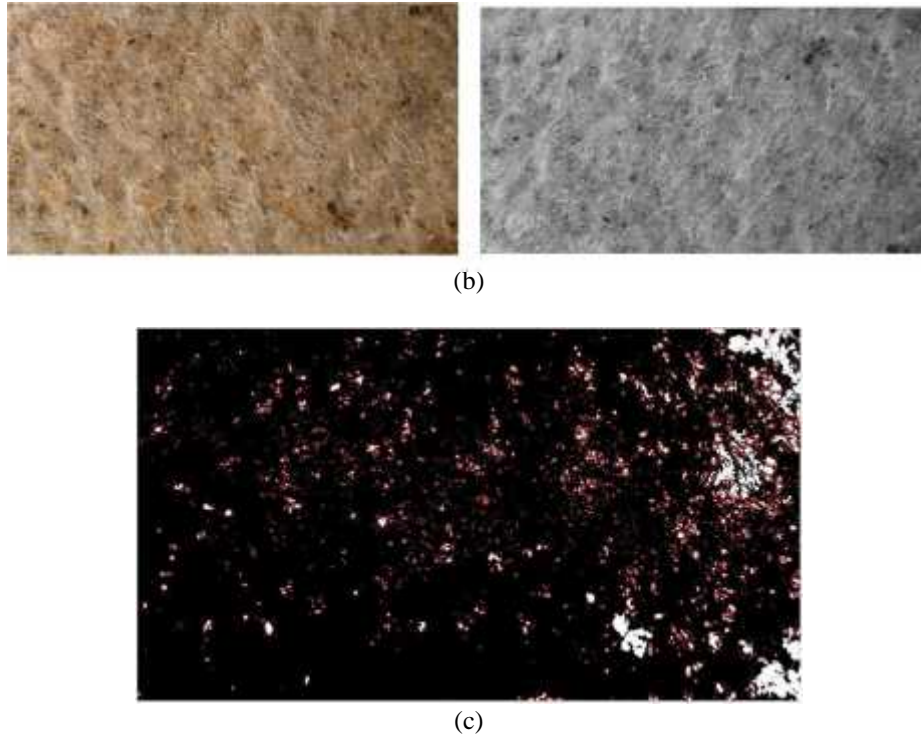
The results have indicated that the Msand particles are less circular than the river sand particles, thus providing greater surface area. It is also indicative that the shear surface area occupied by the Msand particles are more than river sand. The values of convexity indicate that Msand particles are rougher than river sand and provide better interlocking with the GCL interface.

### 5.2 Assessment of changes to the interfacing surface of tested GCL

The shearing interface of GCL with the base materials was analyzed for the changes due to shearing with different interfacing base materials. The images of the tested specimens were captured using Sony HDR-XR550 and analyzed in MATLAB (Fig 10).



(a)



**Fig. 10.** (a) Original untested GCL & greyscale image (b). tested GCL and Grey scale image and (c) Entrapped sand particles captured with segmentation of image in image analysis

The results of the analysis show that the entrapped particles on the surface of GCL when tested in dry conditions are comparable (Table 5.2) However, with the hydration of the specimens the entrapped particles on the GCL-river sand interface increases significantly compared to the GCL-Msand interface. This is attributed to the swelling of bentonite which results in pull-out of reinforcing fibers leading to entanglement at interface. The swelling of bentonite is significantly more in GCL-river sand interface owing to more hydration of GCL specimens when compared with GCL-Msand interface as indicated in Table 5.3. Hence as the swelling is more, the pull-out of fibers associated with swelling is more, leading to entrapment.

**Table 5.2** Entrapment of sand particles

Moisture Content (%)	RS Coverage area (%)	MS Coverage area (%)
<b>0</b>	3.44	2.29
<b>12</b>	33.13	14.3
<b>25</b>	35.55	20.8

**Table 5.3** Moisture content analysis

Tested specimen	Weight of tested specimen (g)	Weighted of dried specimen (g)	Water content (%)
GCL-MS	138	121	14.04
GCL-RS	141	115	22.61

## 6 Conclusions

The interface shear tests conducted on GCL-Msand and GCL-River sand interfaces shows higher shear strength for former and the superiority in performance becoming more evident at higher displacement levels. The reason for the better performance is attributed to the higher frictional resistance and adhesion developed in the GCL-Msand interface due to better interlocking owing to the shape of particles as seen from the results of shape analysis. The analysis of microscopic images of the sand particles showed lower convexity values for Msand, owing to which they exhibit roughness and consequently more frictional resistance.

The study further focused on assessment of changes to the shearing surface of GCL when tested with river sand and Msand. Images of GCL surface prior to and after the testing were analyzed to quantify the particle entrapment. The GCL-River sand interface showed significantly higher entrapment of particles. The hydration of the GCL is the root cause of the entrapped particles and the suction from the river sand is found to be higher than from Msand.

The study concludes that the manufactured sand fulfills the criteria for the subgrade material to be used with GCL in liner applications. The performance of GCL-Msand has been found to be significantly better than GCL-River sand. So in areas where the shortage of river sand is acute, manufactured sand can be used as a viable alternative.

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