VARIATIONS IN INTERFACE SHEAR STRENGTH DEVELOPMENT OF GEOSYNTHETIC CLAY LINER WITH MANUFACTURED SAND

Anjali Pillai, PhD Student, Department of Civil Engineering, Indian Institute of Science, Bangalore, India
Gali Madhavi Latha, Professor, Department of Civil Engineering, Indian Institute of Science, Bangalore, India

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 (Msand) 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 Msand-GCL interfaces to obtain interface friction angle of both these interfaces. The variations in the shear strength parameters are further analysed 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 Optical 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

Geosynthetic clay liners (GCL) are prefabricated geocomposites used as an alternative to composite clay liner to perform the function of hydraulic barriers. The design of engineered landfills aims at maximizing the containment and minimizing the land area which requires steep side slopes and inclined base liners. The failure assessment of many landfill failures has identified the inadequate interface shear strength between the cover components i.e., geosynthetic-geosynthetic or geosynthetic-soil interfaces, to be the primary reason which evoked the failure. Typically, GCLs consist of woven and non-woven geotextile encapsulating a layer of bentonite which can be bonded by needle punching or stitch bonding. The evaluation of interface shear strength between geosynthetic interfaces have been explored over the decades.

Numerous studies have highlighted the shear strength behaviour of geomembrane/soil interfaces. The proposed mechanism of failure for geomembrane surface was sliding and plowing [2]. In the interface of geomembrane/GCL, the laboratory tests revealed the extrusion of bentonite through geotextile into the interface and established GC/bentonite contacts [4,1]. The interface and internal shear strength of geosynthetics are studied with shear tests and the assessment of their strength is analysed with peak and residual values [3]. Significant insight has been obtained on the interface strength of GCL with geomembranes by numerous studies [5]. However, the strength assessment of GCL with base materials have not been explored in detail. The studies related to GCL and subgrade soil has been able to ascertain the effect of subgrade on internal erosion of GCL [6]. The bonding between the GCL and base material is corelated with the frictional characteristics associated with the morphology of the interacting particles. This plays a crucial role in the slope stability of the landfills. From recent studies sand has been identified as an appropriate material for establishing frictional characteristics. The frictional resistance provided by sand is attributed to the size and shape parameters which is the primary factor for establishing interface strength. The identification and differentiation of the shape and size parameters have been done with image analysis that quantifies the shape and size among the particles[7].

In recent decades, the waste generation has seen exponential increase making it mandatory to construct new landfill units. Owing to the shortage of land and appropriate natural subgrade, huge quantities of sand is required to construct the required subgrade. In countries like India, the sand extraction has increased to alarming rates leading to adverse impact like changes in channel morphology, destruction of riparian habitats.

The present study focusses on this compulsion to replace natural sand with a viable alternative. In recent years, the manufactured sand (Msand) has been used as a substitute for natural sand in manufacturing process of concrete. Msand is basically crushed rocks like granite and gneiss and are eco-friendly substitute. In this study, the focus is to replace natural sand with Msand as a base material for GCL and assess the variation in the interface shear strength when tested with modified direct shear setup. The preliminary studies focus on the gradation and chemical composition of natural sand and Msand. The assessment of changes to the interfacing surface is done with image analysis to ascertain the notion of replacement.

2. MATERIAL CHARACTERISTICS

2.1 Geosynthetic Clay Liner

The GCL used in this study consisted of bentonite encapsulated between a non-woven geotextile as basal layer and a woven geotextile as upper layer, needle punched together for maximum performance. The specifications pertaining to GCL is listed in Table 1.

Table 1. Specifications of GCL

Geotextile Characteristics	
Basal layer	Nonwoven geotextile
Upper layer	Woven geotextile
Polymer	Polypropylene
Bentonite Characteristics	
Type	Sodium bentonite
Specific weight (g/cm^3)	2.60
Melting point (°C)	1340
Montmorillonite content (%)	>70
Water absorption (%)	>650
Free swelling capacity (ml/2g)	>24
Composite Characteristics	
Mass per unit (g/m^2)	4300
Nominal thickness (mm)	6.0
Permeability (m/sec)	5×10^{-11}
Tensile strength (longitudinal) (kN/m)	11.5
Elongation (longitudinal) (%)	<20
Static puncture resistance (CBR)	2.2

2.2 River sand and Msand

The initial studies were conducted on the base materials- river sand and Msand to acquire information of the morphological and compositional aspect. The gradation plot as shown in Fig 1 categorises river sand to be medium to fine grained sand and Msand as medium grained sand. Based on the IS code of classification, the river sand and Msand are categorized into SP and SW respectively. The gradation was tweaked to the average of both and obtained as target gradation as shown in Fig 1. This was adopted to simulate identical test conditions by minimizing the effect of size of particles on interface shear.

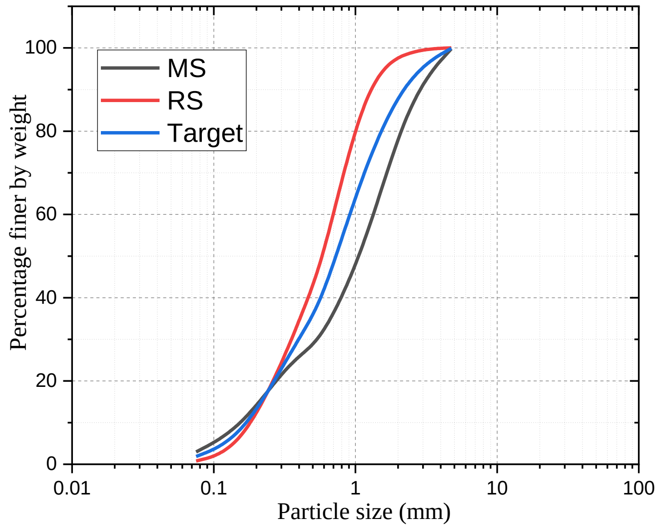


Figure 1. Gradation plots of Msand (MS) , river sand (RS) and target gradation.

To understand the chemical adaptability of both materials, X-ray diffraction was performed which highlighted the chemical composition in terms of silica, alumina and calcium oxides as shown in Fig 2.

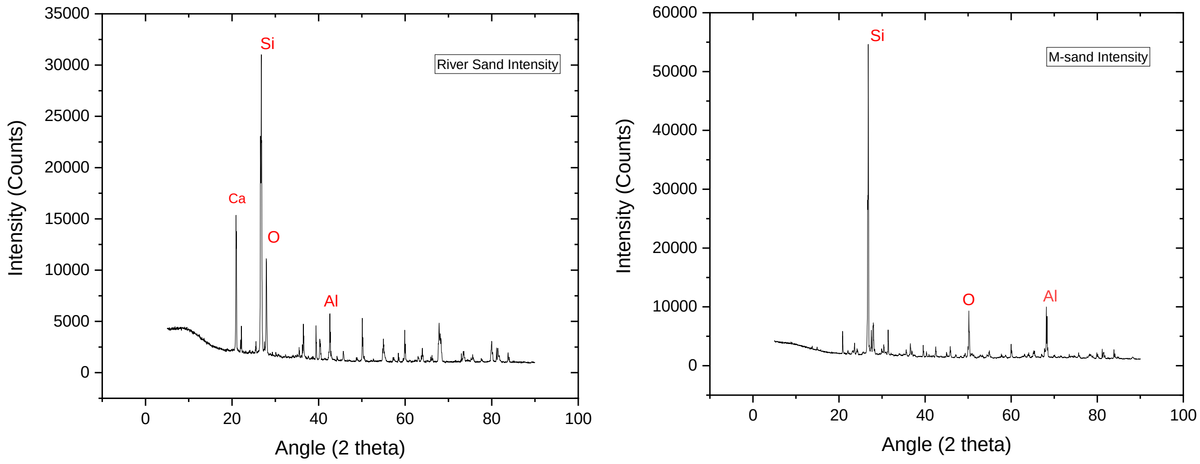


Figure 2. XRD analysis of River sand (left) and Msand (right)

3. EXPERIMENTAL SETUP

The interface shear strength was evaluated by modified direct shear setup in which the lower half of box was replaced by platform on rollers, to which the specimens were fixed. The specimens were cut out in required dimensions from the factory roll (Fig 3). The target gradation of the soil sample was sieved out from both; river sand and Msand. The first phase of interface shear testing was carried out under normal stresses of 30kPa, 60kPa and 100kPa for air-dried samples by changing the interfacing surface from non-woven to woven. The second phase of testing was conducted on samples with the normal stress of 100.67kPa and moisture content of 12% and 25%. The lower and higher bound of moisture content was fixed based on the literature studies of natural moisture content in sand. The shearing was done for a maximum horizontal displacement of 15mm and shearing rate of 0.625mm/min

Figure 3. Factory roll and cut out specimens of GCL

4. RESULT AND DISCUSSION

The analysis provides an insight into the use of Msand as a suitable interfacing material to be used with GCL based on the interface shear strength exhibited by the base materials interfacing with GCL. The variation in performance of non-woven and woven geotextiles of GCL provides an understanding of the interface behaviour. Further, the change in moisture conditions pertaining to the subgrade highlights the changes in the interface shear strength due to the high suction of the bentonite within the GCL. The following sections highlights the important aspects of the analysis.

4.1 Assessment of shear strength in dry conditions

The plot 4.1(a)-(c) shows the variation of shear strength with increase in horizontal displacement for normal stresses of 30 kPa, 60 kPa and 100 kPa for both non-woven and woven interfaces.

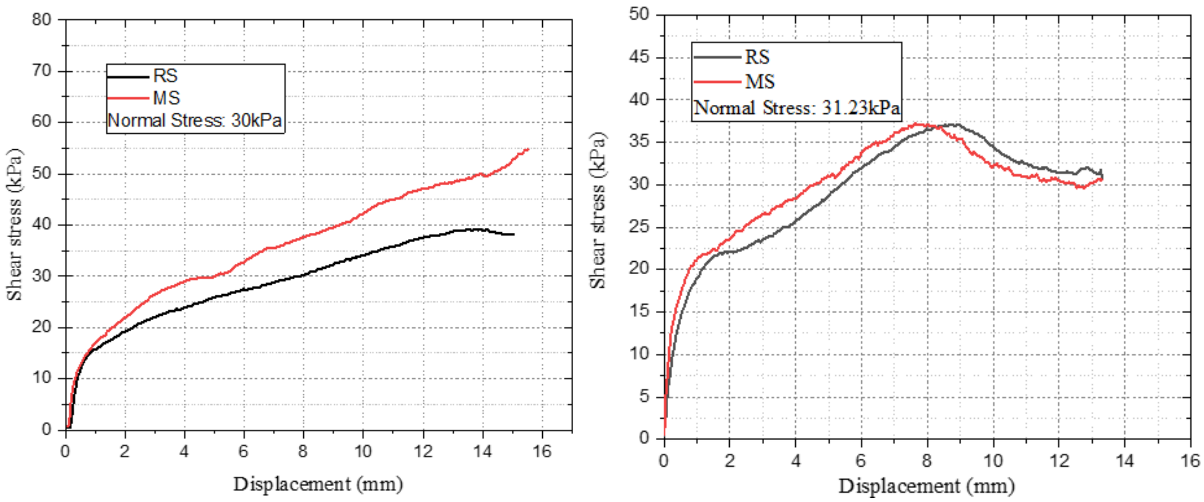


Figure 4.1 (a) Shear stress v/s displacement - non-woven (left) and woven (right)

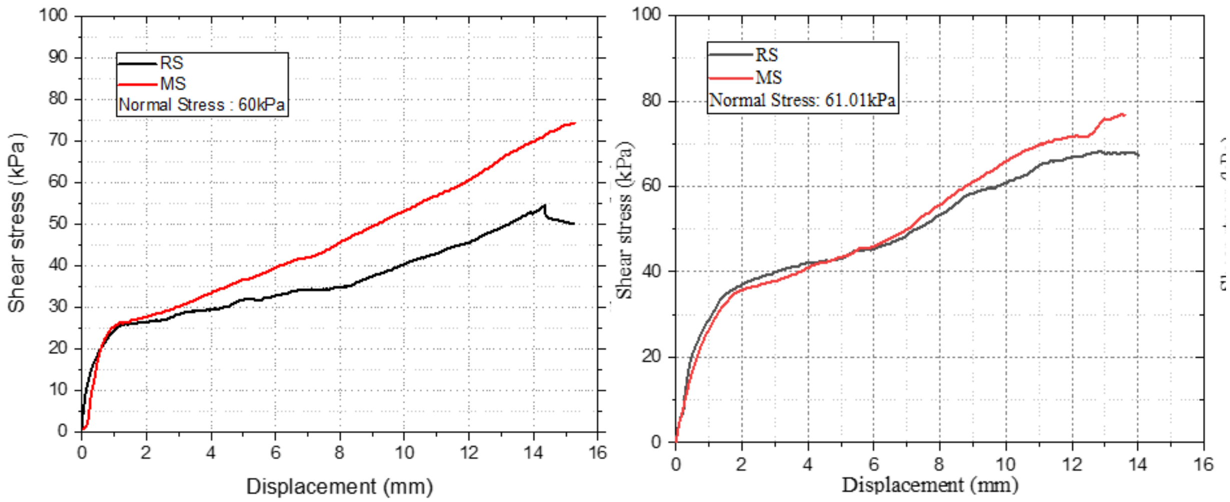


Figure 4.1 (b). Shear stress v/s displacement – non-woven (left) and woven (right)

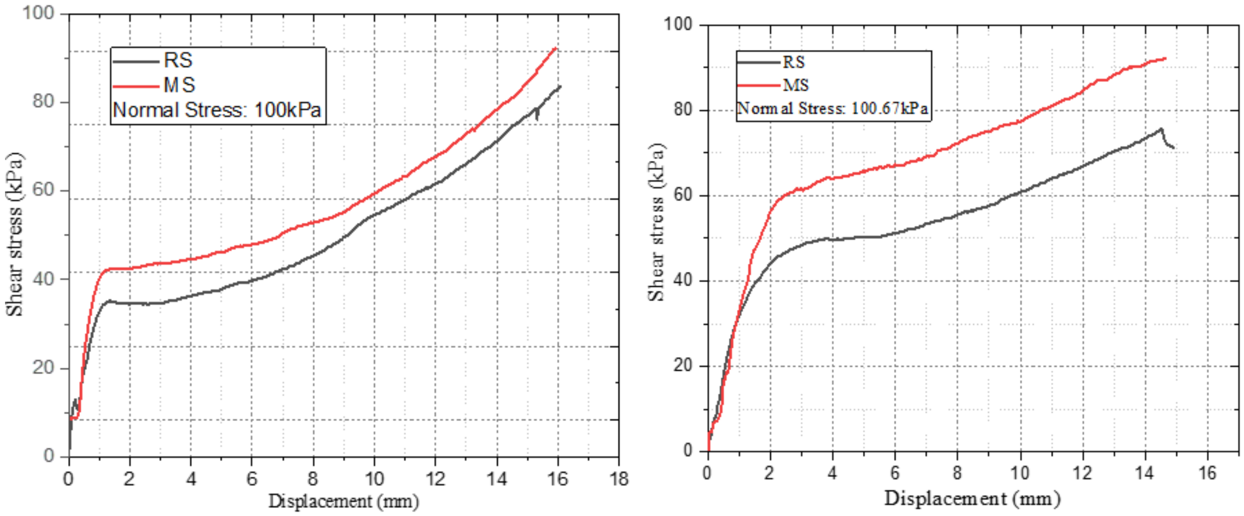


Figure 4.1 (c). Shear stress v/s displacement – non-woven (left) and woven (right)

The comparison of peak shear stress shows a significant increase for GCL-MS interface as to GCL-RS interface. The peak shear stress values attained are higher in non-woven interface compared to woven interface, indicating a better interlocking of sand particles with the fibres of non-woven geotextile. The interface behaviour at woven interfaces were comparable for both, GCL-MS and GCL-RS interfaces when tested in low normal stresses. However, there is an improvement in peak shear stress for GCL-MS interface when tested for high normal stress.

The assessment of shear strength parameters is done by Mohr-Coulomb failure criteria. The failure criteria is obtained for peak shear stress at interface (τ(p)) that specify two parameters, interface adhesion (a(p)) and interface friction (Φ(p)) and is given by

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

The plots in Figure 4.2 shows the variation of peak shear stress with normal stress for both non-woven and woven interface. The linear and bi-linear failure envelope obtained for non-woven and woven interfaces respectively, shows the variation in the interface shear strength in terms of the interface friction (Φ(p)) and interface adhesion values (a(p)). The bilinear envelope is evaluated for two stress ranges and the values are listed in Table2. Based on the interface shears strength parameters, the non-woven interface gives a reliable performance.

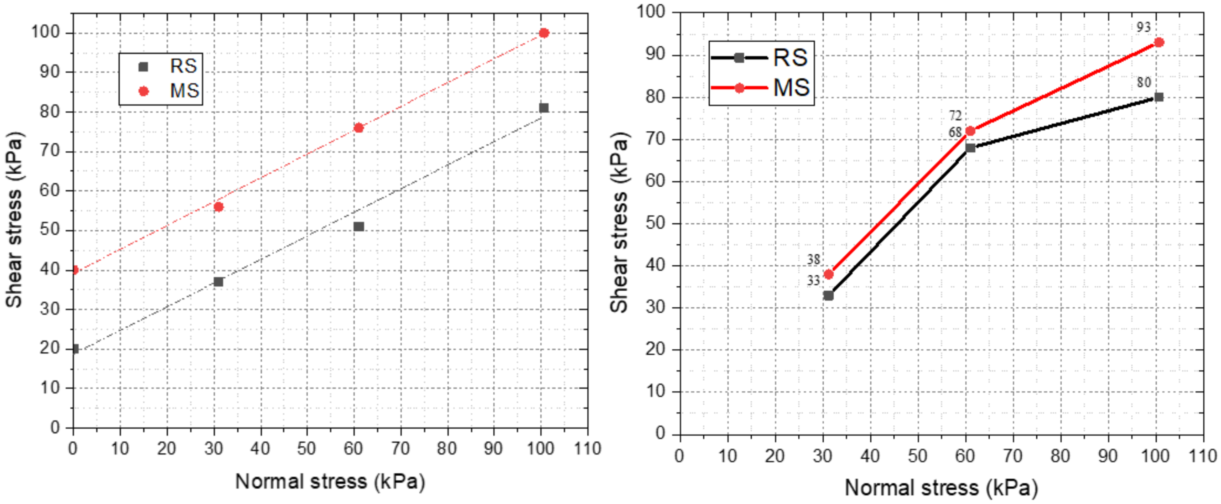


Figure 4.2. Shear stress v/s normal stress – non-woven (left) and woven (right)

Table 2. Interface shear strength parameters

Interfaces	Φ(p)	a(p) kPa
Non-woven		
GCL-MS	33º	40
GCL-RS	31º	22
Woven		
	Normal stress range: 0-60 kPa	
GCL-MS	45.9	7
GCL-RS	45	3
	Normal stress range: 60-100 kPa	
GCL-MS	16.7	64
GCL-RS	5.71	62

4.2 Hydration of GCL with subgrade moisture conditions

Bentonite, encapsulated in GCL, exhibits a volumetric expansion of 900% upon hydration. The influence of hydration of GCL in the interface studies are underestimated. The hydration of GCL occurs in following circumstances:

a. through the punctured hole in geomembrane, which enables hydration though contained liquid in liners where the interface is between GCL-Geomembrane.
b. through suction from subgrade material.

In field the moisture content of the subgrade and cover material can alter due to changes in groundwater levels or due to infiltration of rainwater, which can lead to hydration of GCL through suction. In this study the effect of suction from base materials was analysed to understand the variations in the interface shear strength for the two interfaces: GCL-MS and GCL-RS.

The tests were conducted at moisture content of 6%, 12% and 25% for maximum normal stress of 100 kPa to initiate favourable conditions for suction. The Fig 4.3 shows the variation of shear stress for both the interfaces; GCL-MS and GCL-RS. From the plots, a significant decrease in interface peak shear stress can be identified for both interfaces. The decrease is attributed to swelling of encapsulated bentonite which leads to pull-out of reinforcing fibres leading to reduction in shear strength. The pores of non-woven geotextile further enable the extrusion of bentonite into the interface which reduces the frictional strength. The shear strength parameters are listed in Table 3.

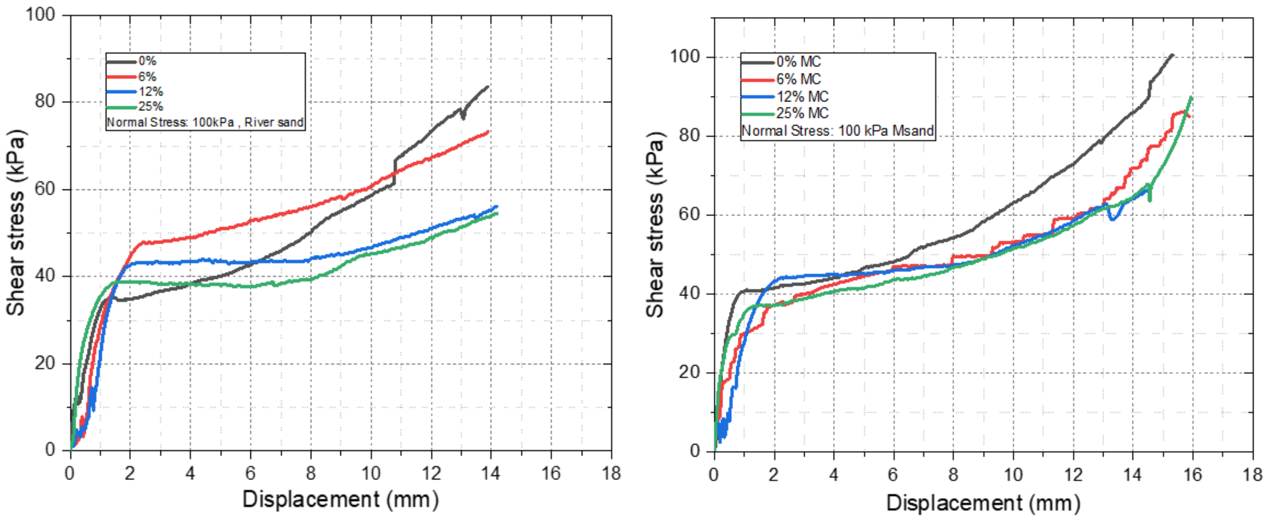


Figure 4.3 Shear stress v/s Displacement for 0%, 6%, 12% and 25% moisture content.

Table 3. Shear strength parameters under hydration conditions

Non-woven Interfaces	Φ(p)	a(p) kPa
GCL-MS	21.75º	38
GCL-RS	19.79º	18

5. IMAGE ANALYSIS

Image analysis was an extensively used technique to characterize and obtain useful information from the images. The image acquisition can be done with SEM, optical microscope or high-resolution camera. In this study the morphological characterisation of particles was done with optical microscope imaging and image analysis in MATLAB. Further, the changes to the shearing surface of GCL was assessed to provide an insight into the behaviour exhibited at the interfaces.

5.1 Particle shape analysis

The size and shape of granular material governs their shear behaviour. In this study, the effect of particle size was minimized by maintaining identical gradation for both materials in all the tests. The variation in the shear strength can be attributed to the difference in shape of the interacting particles. Convexity, circularity, aspect ratio, etc are the commonly used descriptors for particle shapes. The study involves characterization of the river sand and Msand based on shape parameters through image analysis.

5.1.1 Image acquisition and image segmentation

Images of particles were captured using Nikon eclipse 80i optical microscope and the Q-Imaging Micropublisher imaging system was used to capture the images at 20x magnification. 125 particles for each of the three dominant size ranges (1.18mm, 0.6mm and 0.3mm) were analysed The captured images were converted to grey scale and the segmentation of particles was done using MATLAB. The Figure 5.1 (a) and (b) shows the greyscale and segmented image of the sand particles. The images clearly show more pointed edges and irregularity for Msand particles than river sand.

5.1.2 Image analysis

The images were analysed for aspect-ratio, circularity, convexity and elongation to quantify the shape of particles using MATLAB. Circularity shows its resemblance to the circle, value being 1 for circle. Convexity indicates the form of particle. Lesser value indicates more irregularity of edges. The result of analysis is tabulated in Table 4.

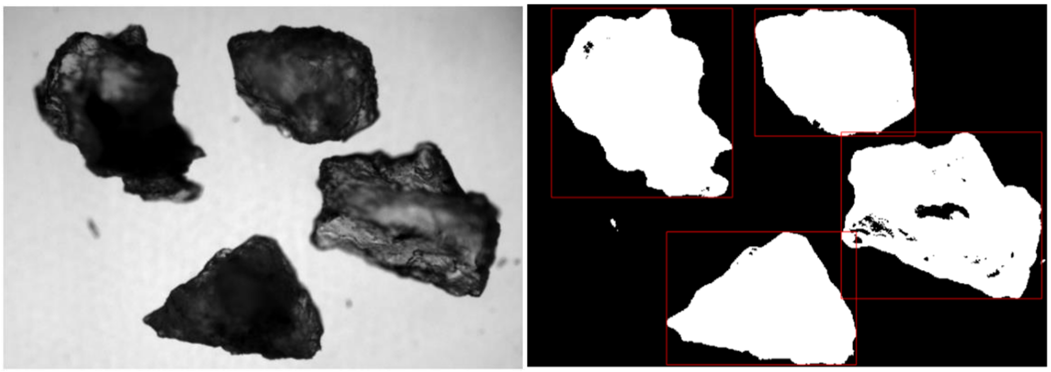


Figure 5.1 a. Image of Msand particles: greyscale (left) and segmented (right)

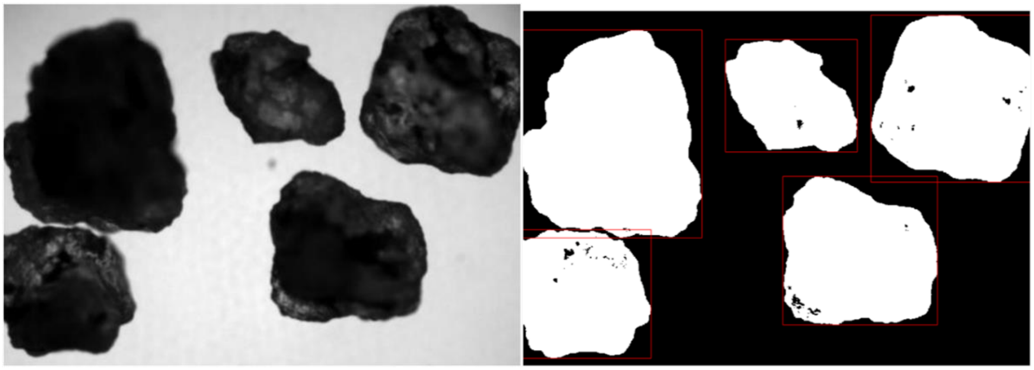


Figure 5.1 b. Image of River sand particles: greyscale (left) and segmented (right)

Table 4. Particle shape parameters

Size -1.18mm	Aspect ratio	Circularity	Convexity	Elongation
River Sand	0.8509	0.7192	0.9125	0.1491
Msand	0.7145	0.7123	0.9077	0.2855
Size – 0.6mm				
River sand	0.8420	0.8020	0.8927	0.158
Msand	0.8166	0.7823	0.9075	0.183
Size – 0.3mm				
River sand	0.8213	0.8910	0.9229	0.1787
Msand	0.7439	0.7260	0.8791	0.2561

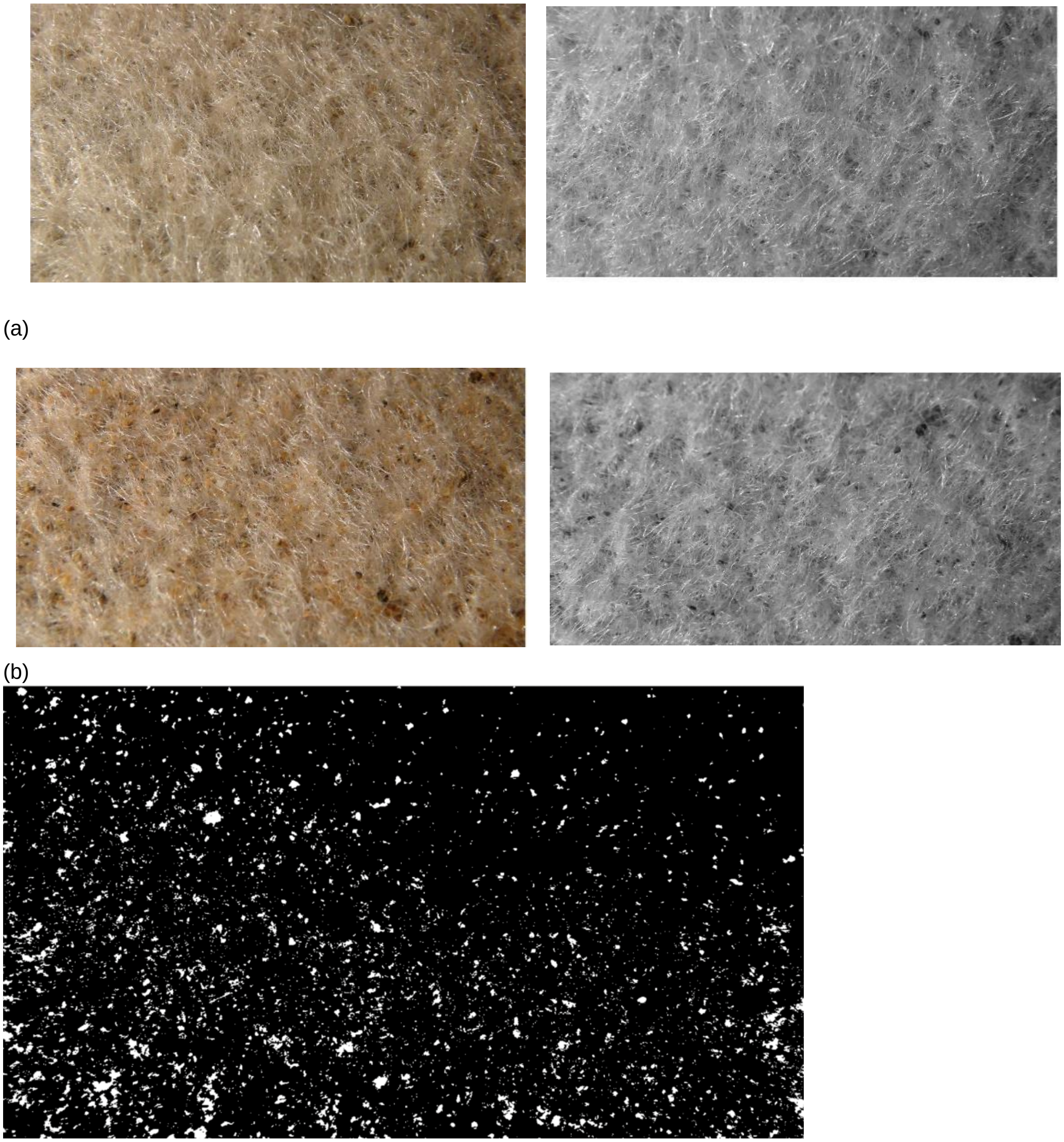
The values of circularity and elongation indicate that the particles of Msand subgrade are more elongated and less circular providing greater surface area and the shear surface area occupied by Msand is statistically greater than River sand particles. The convexity is an indication of the surface roughness of the particles (smoother the particle more will be the convexity). The values of convexity show that the MS particles are rougher than the RS particles providing better interlocking and more friction on the shear interface.

5.2 Surface changes of GCL

The shearing interface (non-woven) of GCL was analysed to understand the variation in entrapment of particles which showed a significant difference upon hydration. The untested and tested surface of GCL specimens were analysed to obtain the difference in terms of area occupied by the entrapped particles. The images were captured using Sony HDR-XR550 and analysed in MATLAB.

5.2.1

The images of untested and tested specimens were obtained and analysed. Fig 5.2 (a)-(c) shows the captured images and the entrapped particles after image analysis in MATLAB.


(a)

(b)

Figure 5.2 (a). Untested GCL specimen: camera image (left) and greyscale (right). (b) Tested specimen: camera image (left) and greyscale (right). (c) Analysed image with sand particles in white.

The results of analysis are tabulated in Table 5. It shows that entrapment of particles is comparable for both interfaces when tested in dry condition. But with increase of moisture content and subsequent hydration of GCL specimens, the entrapment of particles increases significantly. This is attributed to the swelling of bentonite within GCL that results in pull-out of the reinforcing needle punched fibres and extrusion of bentonite on to the interface forming a slimy sticky layer. The values highlight a higher entrapment for GCL-RS interface which indicates more hydration of specimens when tested with river sand. The swelling pressure developed is higher with more hydration indicating a significant damage to the reinforcing fibres leading to lower shear strength at interface.

Table 5. Entrapment of sand particles

Moisture Content (%)	River sand Coverage area (%)	Msand Coverage area (%)
0	3.44	2.29
12	33.13	14.3
25	35.55	20.8

6. CONCLUSION

Interface direct shear tests on river sand and Msand interfacing with GCL showed a higher peak shear stress for GCL-MS interface compared to GCL-RS interface, the superiority in performance becoming significant with higher displacement levels. The reason for the better performance of GCL-MS interface was due to the shape characteristics of Msand particles, as established by the image analysis of both sand particles. Microscopic images taken from particles of different size ranges from both Msand and River sand showed that Msand particles, in all the tested size ranges, have lower convexity values because of which they exhibit higher roughness leading to higher frictional resistance. The particles of Msand are more elongated and asymmetrical when compared to river sand that undergo natural weathering and erosion.

Further the study also involved the assessment of the changes of the shearing surface of the GCL when tested with River sand and Msand. Images of GCL surfaces, before and after the shear test, showed that particle entrapment into the voids of the non-woven geotextile is higher in GCL-RS interface indicating more hydration of GCL specimens. The hydration of specimens results in swelling of encapsulated bentonite. The increase in swelling pressure results in damage to GCL specimens by the pull-out of reinforcing fibres thereby reducing the interface shear strength.

The study concludes that the manufactured sand fulfils the criteria of suitable subgrade material to be used with GCL in liner facilities. The performance of manufactured sand is significantly better as indicated by the test results. They provide higher interface shears strength and lesser damage to GCL due to hydration with suction. In areas where the shortage of river sand is acute, manufactured sand can be used as a viable material for liners along with GCL.

References

1. Chen, Y.M. and Lin, W.A. (2010). Investigation of mechanisms of bentonite extrusion from GCL and related effects on the shear strength of GCL/GM interfaces, Journal of Geotextile and Geomembrane, 28:63–71
2. Fleming, I.R., Sharma, J.S. and Jogi, M.B. (2006). Shear strength of geomembrane–soil interface under unsaturated conditions. Journal of Geotextile and Geomembrane, 24:274–284
3. Marr, W.A. (2001). Interface and Internal Shear Testing Procedures to Obtain Peak and Residual Values. Proceedings of 15th GRI Conference: Hot Topics in Geosynthetics II, Geosynthetic Institute, 475 Kedron Avenue, 88-109.
4. Rowe, R.K. (2018). Geosynthetic clay liners: Perceptions and misconceptions. *International Conference of Geosynthetics*
5. Sochan, A., Zieliński, P., and Bieganowski, A. (2015). Selection of shape parameters that differentiate sand grains, based on the automatic analysis of two-dimensional images*. Journal of Sediment. Geol*., 327: 14–20.
6. Vukelic A., Szavits-Nossan A., Kvasnicka P. (2008) The influence of bentonite extrusion on shear strength of GCL/geomembrane interface. *Journal of Geotext Geomembr* 26:82–90
7. Zanzinger, H. (2016). Contribution to the Long-Term Shear Strength of a Needle Punched GCL*. Int. J. Geosynth. Gr. Engg.*, 2: 8.