Hydro-mechanical behavior of glass fiber reinforced clay barriers

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Abstract. The current study highlighted the inclusion of glass fiber reinforcement on various hydro-mechanical properties such as volumetric shrinkage, suction, compressibility and hydraulic conductivity of the clay. The effect of electrolyte on the compressibility and hydraulic conductivity of the clay and reinforced clay soil was studied using two NaCl salt concentrations of 0.5 and 1molarity. The results showed, increase in glass fiber content leads to increases the total suction and hydraulic conductivity of clay marginally, whereas, compression index was found to be decreased. For 1M NaCl concentration, the compression index of the clay and reinforced clay soils were found to be decreased by about 31% and 19%, respectively. However, the hydraulic conductivity of the clay and reinforced clay was noted to be increased by about 35 and 9 times, respectively. Therefore, the glass fiber can be used as an effective reinforcement material for contaminated barrier materials to improve its properties.

Keywords: Clay, Glass fiber, Compression index, Hydraulic conductivity, Saline fluid.

1 Introduction

The compacted clays are used as potential barrier materials for most of the municipal solid waste disposal. Due to the scarcity of high-quality bentonites, bentonite has been mixed with sand or clays and used as clay liners. The desiccation process in clays leads to form high shrinkage cracks, which caused to increase in the hydraulic conductivity significantly. In order to reduce desiccation cracking, various types of reinforcement materials such as natural fiber (coir, jute), synthetic fibers (polypropylene fibers, polyethylene fibers, polyester, polyvinyl alcohol fibers and Glass fibers, etc.) are extensively used as reinforcement materials in the clay barrier materials (Mukherjee and Mishra, 2016). The effect of fiber reinforcement on hydraulic conductivity and desiccation cracking of expansive clays was investigated by several researchers (Chaduvula et al., 2017; Abdi et al., 2008; Malekzadeh and Bilsel, 2014). The above studies were concluded that the inclusion of reinforcement leads to decreases the volumetric cracks and increase in hydraulic conductivity marginally. Divya et al., (2018) studied the significance of geo-fiber inclusions on hydraulic conductivity of soils. The study concluded that both the increase in the length and concentration of fiber caused a marginal decrease in hydraulic conductivity of the soil.

Mukherjee and Mishra, (2016) found a decrease in hydraulic conductivity of soils with an increase in the aspect ratio of fibers. To contrast, Miller and Rifai, (2004) observed a significant increase in hydraulic conductivity with increase in an aspect ratio of fibers. The fiber reinforcement changes the soil failure pattern from brittle to the ductile tensile (Li et al., 2014; Divya et al., 2014). Increase the fiber reinforcement leads to increase the unconfined compressive strength (UCS) of soils up to the fiber content of 0.5%, followed by strength decreases for higher fiber concentrations (Ayeldeen and Kitazume, 2017). Similarly, Jiang et al., (2010) observed that 0.3% fiber content was more optimal for stabilization of clays. A uniform increase in UCS with an increase in fiber concentration was noted by Soğancı, (2015). Kar et al., (2012) investigated the influence of fiber reinforcement on consolidation characteristics of cohesive soil. Thyagaraj and Soujanya, (2017) studied the effect of polypropylene fiber for waste containment bentonite barriers.

The effect of various leachate concentration on the hydraulic properties of barrier materials has been studied by many researchers (Mishra et al., 2009; Singh and Prasad, 2017; Tripathy et al., 2014). The above studies suggested that the C_C, m_v, and t_{90} of the bentonites decreased with increases in salt concertation. Further, the increase in electrolyte concentration caused a significant increase in the hydraulic conductivity of the barrier materials.

In the current study, a series of experimental tests were conducted to evaluate the significance of glass fiber reinforcement on various soil properties such as shrinkage limit, volumetric shrinkage, suction, compressibility and hydraulic conductivity of the clay.

2 Materials and methodology

2.1 Materials

Locally available black cotton soil near Bihta village and commercial bentonite procured from Bikaner, Rajasthan, India were mixing 50:50 weight ratios and used in the current study for conducting various experimental tests. The oven-dried black cotton soil passed through 425micron was used for mixing with bentonite. The basic engineering properties of the clay such as specific gravity, Atterberg limits and particle size distribution were determined following standard Indian soil classification system IS 2720 (Part 3, 1980), IS 2720 (Part 4, 1985) and IS 2720 (Part 5, 1985), respectively. The basic properties of clay mixture (50:50) along with bentonite and black cotton soil are presented in Table1. The High tensile strength glass fiber of 10-15mm length is used as reinforced material. The specific gravity and modulus of elasticity of glass fiber was approximately 2.64 and 71 GPa.

Fig. 1. Photograph of the materials used in the study, (a) Mixture clay, (b) Glass fiber

Table 1. Physical properties of mixture clay along with parent soils of bentonite and black cotton soil

Property	Specific gravity	Liquid Limit (%)	Plasticity index (%)	% of clay fraction	IS classification
Bentonite	2.76	234	187	76	CH
Black cotton soil	2.69	41	21	34	CI
Mixture clay(50:50)	2.74	84.5	52.4	58	CH

2.2 Methodology

A series of experiments were conducted to evaluate the effect of glass reinforcement on various clay properties such as shrinkage limit, volumetric shrinkage, suction, compressibility and hydraulic conductivity. The standard compaction tests were performed as per the guidelines of (IS: 2720 Part-7-1980) by using different fiber contents i.e. 0%, 0.5%, 1 and 2%. In order to find out the influence of glass fiber reinforcement on the volumetric shrinkage of the clay, the standard unconfined compressive strength (UCS) soil specimens of 36 mm diameter and 72 mm height were directly extruded from standard compaction mold to the corresponding MDD and OMC of different percentage of reinforcement condition. The initial void ratio of the extruded clay sample was noted as e_0. After that, soil specimens were allowed to dry at room temperature and followed by oven-dried at 110°C for 24 hrs.

The volumetric shrinkage noted as Vs = $\frac{e_0 - e_f}{1 + e_0} \times 100$ (1)

where e_o and e_f are the void ratios in compacted and shrunken states, respectively (Thyagaraj and Soujanya, 2017). The inclusion of glass fiber on the shrinkage limit of the clay was determined as per IS 2720 (Part 6, 1972). The effect of glass reinforcement on total suction of clay was determined by using WP4C device. The soil samples which were collected from compaction tests were used for suction measurement. The total suction at different gravimetric water contents was determined by drying soil specimens in the room temperature. Triplicate measurement was carried out for each percentage of reinforcement and the average suction values were reported in the current study.

The effect of glass reinforcement on the compression index and hydraulic conductivity of the clay soil has been investigated using consolidation tests IS 2720-15 (1965). The oedometer clay specimens were prepared at a water content equal to the liquid limit by mixing clay with various percentages of glass fiber such as 0%, 0.5%, 1%, and 2%. On the other hand, the effect of electrolyte concentration on the compression index and hydraulic conductivity of the clay soil and reinforced clay soil was studied using two NaCl concentrations 0.5 and 1M at a fixed reinforcement content of 1%. The liquid limit of the clay found to be 48.4 and 42 to the corresponding NaCl concentration of 0.5 and 1M. The required quantity of the clay paste was carefully transferred to oedometer rings of size 60 mm diameter and 20 mm height. The consolidation tests were started with an initial pressure of 5 kPa to the maximum stress applied about 800 kPa. The compression index C_c was calculated as the slope of the straight-line portion of the virgin void ratio-effective stress (e-log P) curve.

$$C_c = \frac{e_i - e_j}{\log(\frac{p_i}{p_j})} \tag{2}$$

where e_i and e_j are the void ratios corresponding to the consolidation pressure of P_i and P_j at i^{th} and j^{th} steps of loading, respectively (Mishra et al., 2009).

The hydraulic conductivity of the clay was indirectly calculated from the oedometer test results using Terzaghi's consolidation theory.

$$k = c_v m_v \gamma_w \tag{3}$$

where k is hydraulic conductivity, C_v is the coefficient of consolidation, m_v is the coefficient of volume compressibility and γ_w is the unit weight of pore water pressure. The settlement of the soil samples corresponding to various time intervals was recorded by using LVDT. The coefficient of consolidation (C_v) values of the clay was determined from Taylor's square root time (√T) method.

3 Results and discussion

3.1 Effect of glass reinforcement on shrinkage limit and volumetric shrinkage

The effect of glass fiber reinforcement on the shrinkage limit and volumetric shrinkage of the clay is presented in Fig. 2. The results indicated that with an increase in the percentage of reinforcement shrinkage limits increases, whereas volumetric shrinkage decreases.

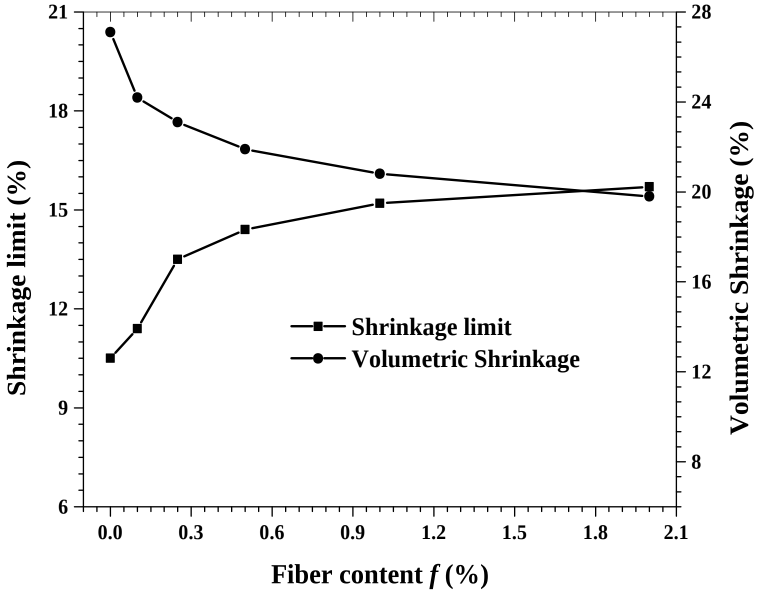

Fig. 2. The effect of glass reinforcement on shrinkage limit and volumetric shrinkage of clay

The addition of reinforcement material caused to increase the ductility and tensile strength of clay resulting in volumetric shrinkage decreases. The reinforcement material attribute to increases the surface contacts in soils, which improves the resistance of soil against the volume change due to the desiccation process. Further, an increase in fiber content leads to a decrease the fiber-fiber spacing in soil, resulting in increases the fiber soil effective contact area. This phenomenon attributed to better crack-bridging (Tang et al., 2012). The increase in shrinkage limit was found to be more pronounced up to 1% reinforcement, followed by the effect was decreased for higher fiber content. Similarly, the volumetric shrinkage was noted to be decreased significantly up to 0.5% of reinforcement. Therefore, inclusion of glass fiber was an effective method to decrease the volumetric shrinkage in clays.

3.2 Effect of glass fiber reinforcement on compaction tests

The effect varioues percentages of glass fiber i.e., 0, 0.5, 1 and 2% reinforcement on the compaction characteristics of clay is presented in Fig. 3. The results indicate that the inclusion of glass fiber does not show any significant effect on the optimum moisture content (OMC) of clay.

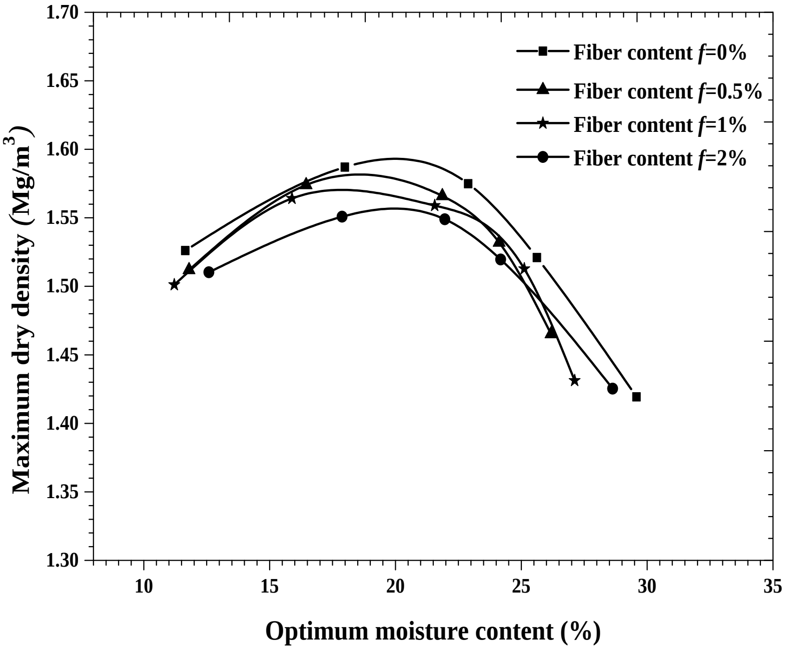

Fig. 3. The effect of glass reinforcement on compaction characteristics of clay soil

However, the maximum dry density (MDD) found to be marginally decreased with an increase in fiber concentration. During increase the fiber content, the lightweight material of the fiber can replace the soil clay particles (Thyagaraj and Soujanya, 2017). This phenomenon reduce the mass of the soil samples, thereby decrease in MDD of clay.

3.3 Effect of glass fiber on suction properties of clay

The inclusion of various percentage glass fibers on the total suction of the clay is illustrated in Fig. 4. The results showed that at the lower suction range below 8MPa, as increase fiber concentration caused marginally increases the total suction of clay. Due to the increase in fiber concentration, the macrospores of the clays could be decreased. Therefore, an increase in suction particularly at lower suction ranges has been noticed. However, at the higher suction range, the inclusion of reinforcement does not show any effect on suction properties. Similar observations reported by Malekzadeh and Bilsel, (2014). The increase in fiber content attributed increase the air entry value (AEV) of clay. The reinforced fiber material may enhance the bonding between the fiber and soil, which can prevent air entry into the soil pores.

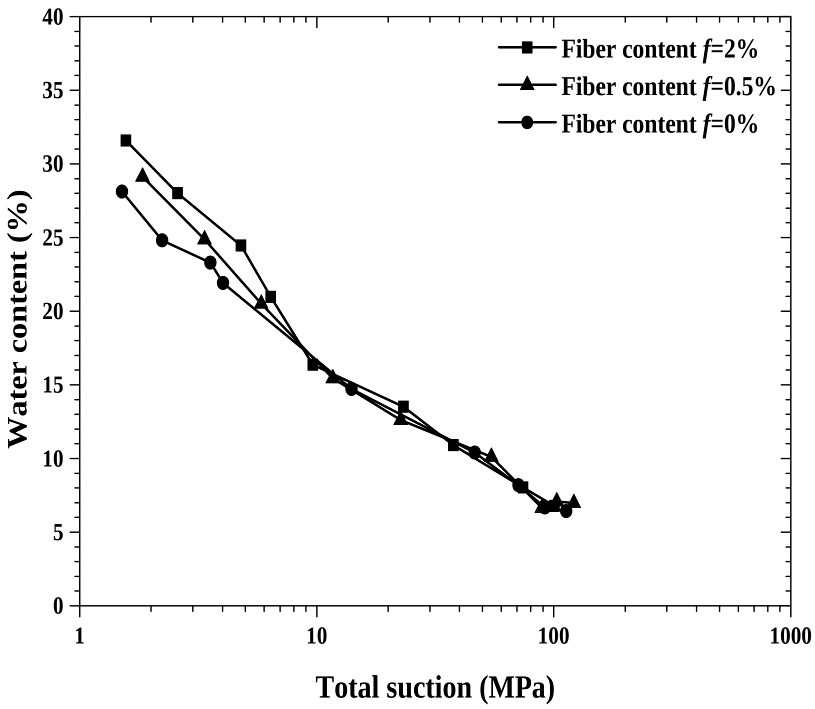

Fig.4. Soil suction versus water content for the clay as a function of fiber content

3.4 Effect of glass fiber reinforcement on compressibility and hydraulic conductivity of clay soil

The effect of glass fiber reinforcement on void ratio versus logarithm effective pressure, (e-logP) and hydraulic conductivity of the clay is presented in Fig.5(a)-(b), respectively. The results indicate that both the compression index and hydraulic conductivity of clay were marginally affected by fiber content. As increase fiber content from 0 to 2%, a marginal decrease in consolidation settlement occurred in the clay samples. Therefore, the compression index was noted to be decreased from 0.94 to 0.8. The percentage decrease in the compression index was found to be 14.5%. The fiber materials caused to increase the mechanical interactions between the fibers and soil particles, resulting in increased soil stiffness. Hence, consolidation settlement decreased at higher fiber concentration. The hydraulic conductivity of the unreinforced clay was noted to be varied from 9×10^{-9} to 5×10^{-11} to the corresponding dry density between 0.84 to 1.88 Mg/m^3. In addition to that at a given dry density the hydraulic conductivity of clay increases marginally with an increase in glass fiber concentration.

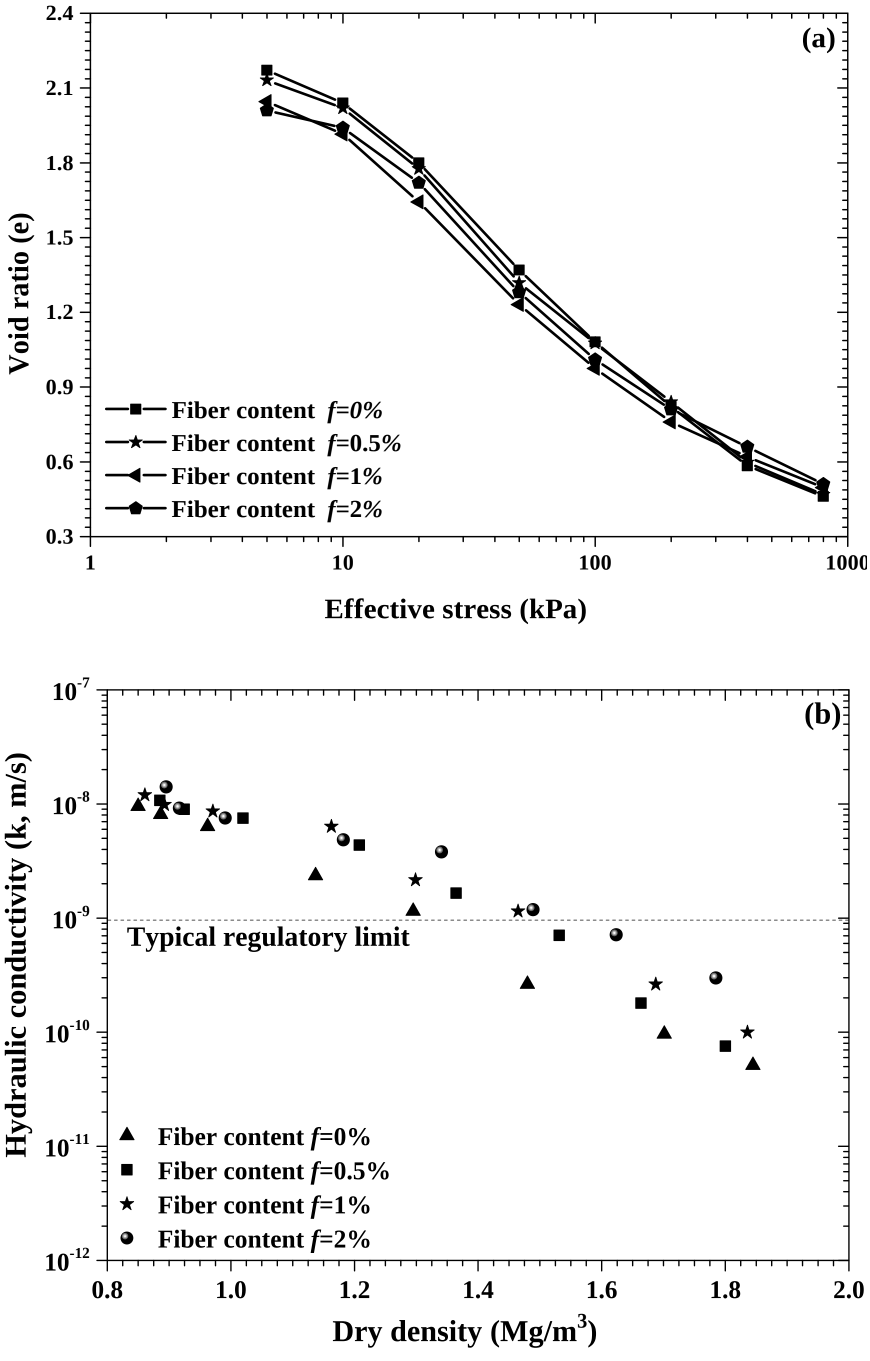

Fig. 5. Effect of inclusion of glass reinforcement on: (a) e-log(p) of the clay; (b) hydraulic conductivity of clay

Increase in fiber concentration from 0 to 2% the hydraulic conductivity of clay was found to be increased about 3.5 times. The similar observation made by Abdi et al., (2008). However, the typical hydraulic conductivity value for landfill liner material is 10^{-9} m/s (Mishra et al., 2009). Therefore, even at higher fiber of 2%, the hydraulic conductivity of fiber-reinforced clay was well below the critical hydraulic conductivity. Therefore, at a higher dry density of more than 1.5 Mg/m^3 the reinforced clays were fulfilling basic criteria of hydraulic conductivity of barrier materials.

3.5 Effete of saline fluid on compressibility and hydraulic conductivity of clay and reinforced clay soil

The effect of saline fluid concentration on both the compressibility and hydraulic conductivity of clay and reinforced clay soil are presented in Fig.6(a)-(b), respectively. The compression index for clay was noted to decrease from 0.944 to 0.65 to the corresponding increase in salt concentration from zero (Deionized water) to 1M of NaCl. On the other hand, for reinforced clay at 1% glass fiber the increase in NaCl concentration from 0 to 1M caused to reduce the compression index from 0.786 to 0.63. The percentage of decrease in the compression index was found to be 31% and 19% for unreinforced clay and reinforced soil, respectively. The increase in salt concentration leads to a significant decrease in the diffused double layer thickness of clays. Therefore, the compression index values of unreinforced clay were decreased significantly with the increase in salt concentration. On the other hand, in case of reinforced clay the effect of NaCl concentration on the compression index was found to be less as compared to unreinforced clay. In the presence of NaCl concentrations, the fiber amended clay experienced less consolidation settlement. The fiber concentration may affect the reduction in DDL thickness of clay. Further, the fiber materials could not allow any compression during the consolidation loading. This phenomenon controls the decrease in the compression index of the reinforced clays.

The results suggested that at a given dry density, due to an increase in NaCl concentration from 0 to 1M the hydraulic conductivity of the clay soil was found to be increased about 35 times. On the other hand, for reinforced clay the hydraulic conductivity was noted to be increased about 10 times. It indicates that unreinforced clay was prone to significantly affected by external pore fluid concentrations. Therefore, depending on the dry densities both the unreinforced clay and reinforced clays were fulfilled the basic hydraulic conductivity criteria as engineered barriers material. However, in the presence of the salt concentration, the hydraulic conductivity of unreinforced clay was significantly increased, whereas lower effect was noticed for reinforced clay. In addition to that, the reinforced clay has experienced less volumetric shrinkage as compared to unreinforced clay.

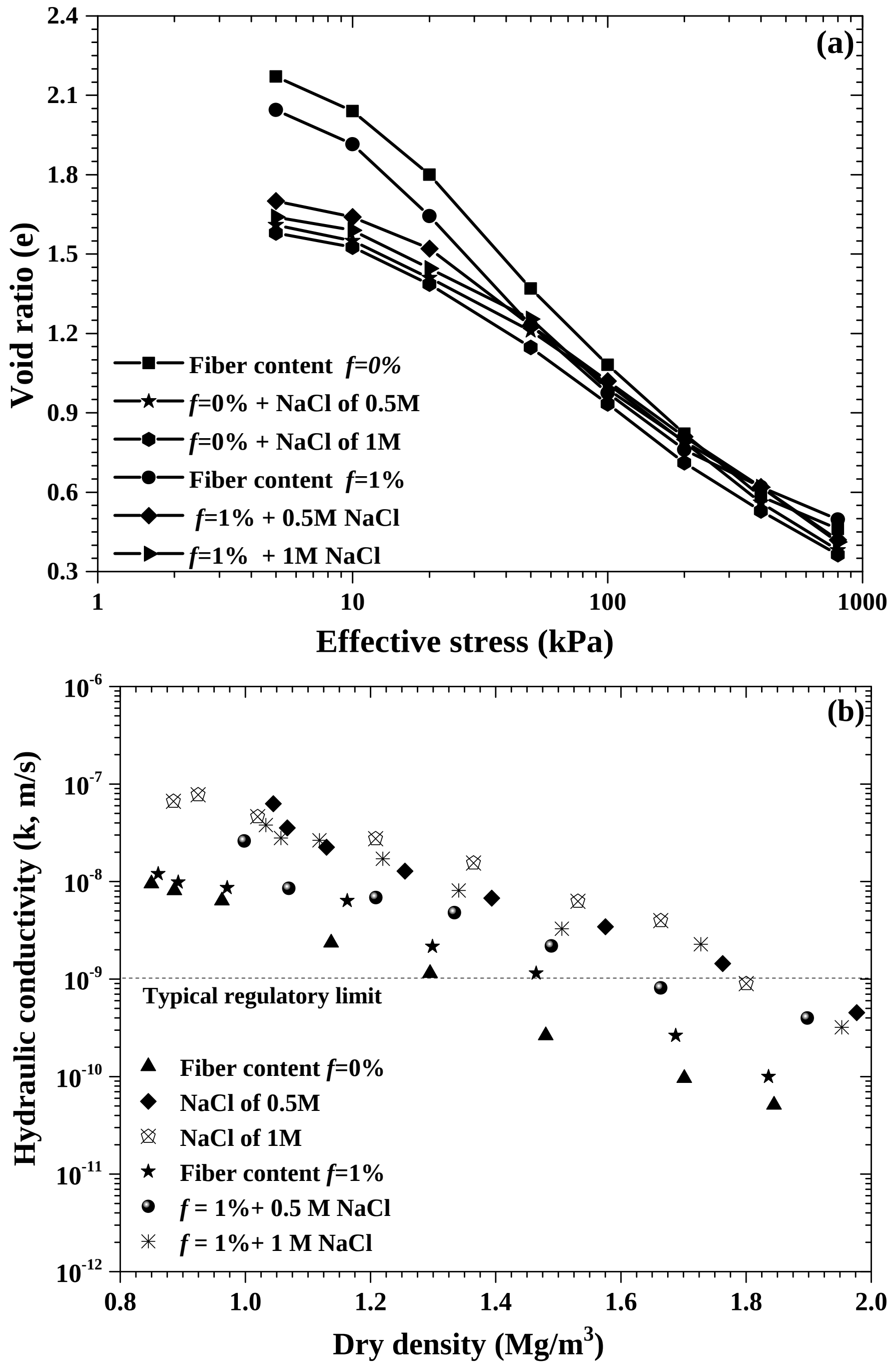

Fig. 6. Effect of saline fluid on: (a) e-log(p) of the clay and reinforced clay; (b) hydraulic conductivity of clay and reinforced clay

4 Conclusions

The current study evaluated the effect of various percentages (i.e., 0%, 0.1%, 0.5%, 1%, and 2%) of glass reinforcement on various properties clay such as shrinkage limit, volumetric shrinkage, suction, compressibility and hydraulic conductivity of the clay. The effect of saline fluids on the compressibility and hydraulic conductivity of the clay soil and reinforced clays were studied. The experimental results revealed that with an increase in percentage of reinforcement the shrinkage limit and volumetric shrinkage found to be incrases and decreases, rspectively. At lower suction range below 8MPa, an increase in fiber content caused a marginally increase in the total suction of clay. Both the compression index and hydraulic conductivity of clay were marginally affected by fiber concentration. An increase in fiber concentration from 0 to 2% the compression index was found to be decreased by 15%. In the presence of 1M NaCl, the compression index of the clay soil and reinforced clay soil was noted to be decreased by about 31% and 19%, respectively. Similarly, the hydraulic conductivity of the clay and reinforced clay soil were found to be increased by about 35 and 9 times, respectively. Therefore, the glass fiber can be used as effective reinforcement material for contaminated barrier materials.

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