EXPERIMENTAL INVESTIGATION OF AGING EFFECT ON SHEAR STRENGTH PARAMETERS OF SAND/GEOSYNTHETIC INTERFACE

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Abstract: Time-dependent behaviour of soils has been investigated extensively using one-dimensional and triaxial test procedures. The phenomena associated with time effects in soils are creep, relaxation, strain rate effects and re-arrangement effects. The engineering properties of soil often improve significantly during aging. The objective of this paper is to investigate the aging effect on the shear strength parameters of sand/geosynthetic interfaces using large direct shear test apparatus. For this purpose, the geosynthetic layer has been adhered gently on a piece of wood with a thickness such that a half of the shear test box has been occupied. The other half box has been filled with the sand and the test has been performed. Three normal stresses of 30, 45, and 60 kPa have been applied in all tests. The shear stress has subsequently been applied in different times to the failure stage. In all tests, the shearing velocity has been kept the same. The results of these experiments show that the stiffness of sand/geosynthetic interface increases with time. This is interesting to consider in practice.

Keywords: sand, geosynthetic, ageing, friction, direct shear test, shear strength

INTRODUCTION

Geosynthetics are used for many soil structures, such as, reinforced earth walls, reinforced slopes, embankments on soft soils, landfills, and foundations. The use of reinforcement objects increases resisting forces in the soil mass through the tensile force provided by reinforcement elements, and consequently reducing the horizontal deformations and increasing the overall stability of the soil structure (Mohiuddin, 2003).

There are two principal issues to be analyzed when designing soil geosynthetic reinforced structures: the development of enough anchorage for the reinforcement (especially in retaining walls and slope reinforcement) and the potential for embankment sliding along the reinforcement (Haliburton et al, 1978). If there is insufficient anchorage length, the failure will happen at the soil reinforcement interface above and below the reinforcement as the reinforcement is pulled out. This phenomenon is known as the "pull-out" mode. If the geomaterial–reinforcement interface strength is less than the shear strength of the soil alone, then the reinforcement represents a plane of weakness. Then, a "direct shear" mode failure occurs. In this mode, a relative movement occurs at the interface of the geomaterial and reinforcement layer on both connecting sides.

The interface direct shear test was standardized by ASTM D 5321 which specified the use of a large conventional shear box machine (300×300 mm) after appropriate modification.

The soil–geosynthetic interaction parameters are influenced by a) Interaction mechanism between geomaterials and geosynthetics (pull-out or direct shear), b) physical and mechanical properties of geomaterials (density, grain shape and size, grain size distribution, water content, and plasticity of clayey soils), and c) mechanical properties (tensile peak strength), shape and geometry of geosynthetics.

It is well established that time dependent property changes after deposition and/or densification occur in clean sand deposits in the field (Mitchell and Solymar 1984; Dumas and Beaton 1988; Schmertmann 1991; Charlie et al. 1992; Ng et al. 1996). These changes, which may be significant over periods of days to weeks, include increases in small strain stiffness and large strain strength, as reflected by increased penetration resistance. They occur after any associated dissipation of pore pressures or measurable changes in the volume.

Currently, there is an uncertainty as to the underlying causes of this phenomenon. Generally, hypotheses fall into two categories: mechanical mechanisms and chemical mechanisms. Mechanical mechanisms assume an increased frictional resistance developed during secondary compression, increased interlocking of particles and surface roughness, and internal stress arching (Mesri et al. 1990; Schmertmann 1991). Chemical mechanisms focus on the dissolution and precipitation of silica or other materials such as calcium carbonate (Mitchell and Solymar 1984; Joshi et al. 1995). However, there is no consensus or incontrovertible evidence to validate either hypothesis.

This paper presents the results of a laboratory testing program to study of time-dependent effect on shear strength parameters of sand–geosynthetic interface using large direct shear test apparatus. Also, in these tests, the thickness of geosynthetic on time-dependent effects was investigated. The specific properties that were observed with time were the shear strength parameters and stiffness of sand–geosynthetic interface.

EXPERIMENTAL PROGRAM

Equipment details

A large direct shear apparatus with dimensions of 300×300 mm was used to carry out the tests according to the procedure described by ASTM. Figure 1 shows a view of the equipment.

Figure 1. Large direct shear apparatus

Three hydraulic actuators controlled by computer facilitate the equipment movements. The horizontal actuator has a maximum load capacity of 50 kN and is connected to a 50 kN tension/compression load cell. Horizontal and vertical displacements are controlled by an internal displacement transducer. The normal stress is applied by lever arm which is connected to a rigid plate with 300×300 mm of loading area.

Properties of materials

The soil used in tests is sand and the main characteristics of the sand are presented in Table 1. Also, the grain size distribution of the sand is shown in Figure 2.

Table 1. Main characteristics of the sand

Property	Value
Minimum void ratio, emin	0.636
Maximum void ratio, emax	0.89
Specific gravity, Gs	2.65
Uniformity coefficient, Cu	1.87
Curvature coefficient, Cc	1.17

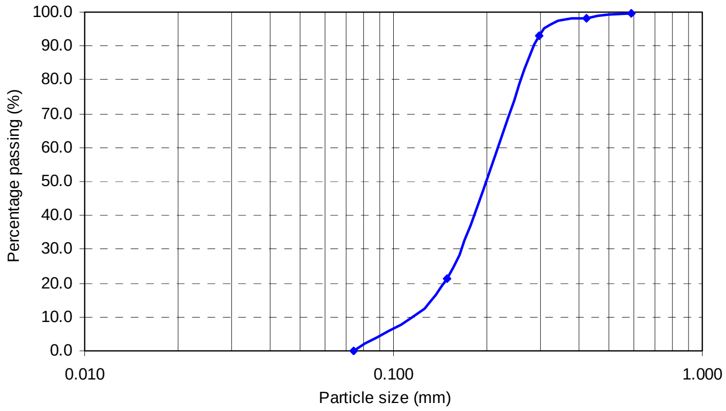


Figure 2. Grain size distribution of sand

The geosynthetic used for tests is needle punched nonwoven geotextile. Table 2 presents the properties of the nonwoven geotextile provided by the manufacturer.

Table 2. Properties of nonwoven geotextile

Product name	Polymer type	Mass per unit area (g/m^2)	Thickness (mm)	Tensile strength (kN/m)	Grab elongation (%)
GTN.20	Polypropylene	200	1.80	14.1	>50
GTN.50	Polypropylene	500	3.80	27	>50

Test procedure

The interface shear tests were conducted at the Geotechnical Engineering Laboratory of the K.N.Tossi University of Technology using a direct shear apparatus. A square base direct shear box (300×300 mm) split horizontally at mid-height was used.

Various methods have been suggested for keeping geosynthetics in place during shearing including clamping (Fox et al., 1997) and gluing (Ling et al., 2001). Clamping was avoided as clamping may increase the likelihood of a progressive failure and thus reduce the measured peak interface shear strength (Fox et al., 1997). In the present study, for simplicity and in order to minimize the potential for any movement of the geotextile during shearing, the geotextile specimen was glued to a wooden block. The wooden block with glued geotextile was kept under compressive stress for one hour to ensure a proper bonding. The application of compressive stress for one hour also helps to reduce elongation of the geotextile during shearing and encourages a sliding type of failure.

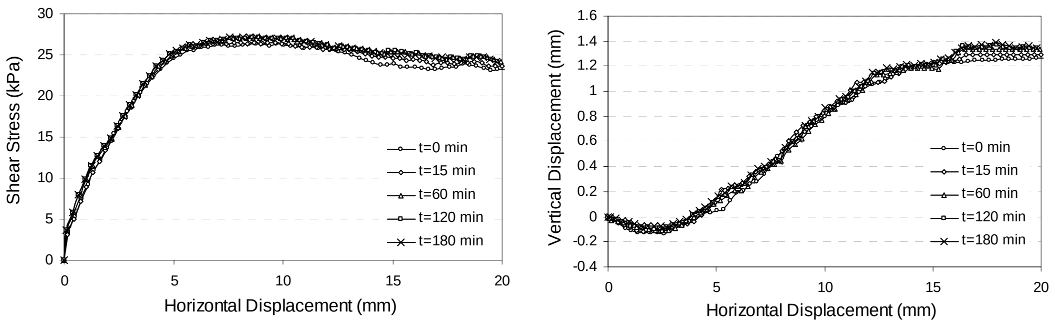
The wooden block-geotextile assembly was mounted in the lower half of the shear box. The sand to be used in the testing was placed at the desired moisture content into the upper half of the shear box immediately over the geotextile surface. A 100×100 mm square tamper was used to compact the soil to the desired density. Then the load plate was rest on the sand and the normal stress was applied and stayed on the sand for a different time and the test has been performed. The elapsed times for applying normal stress were different and included 0, 15, 60, 120, and 180 minutes.

All tests were performed for dry sand. For evaluating the influence of the thickness of geotextile, two types of geotextile were used. In all tests, the sand was compacted to a dry density of 1500 kg/m^3. Three normal stresses of 30, 45, and 60 kPa were applied in all tests. The shear rate selected for all the tests was 0.85 mm/min. All samples were tested under the strain controlled condition.

TEST RESULTS

The direct shear tests were conducted on unreinforced soil samples to evaluate shear strength parameters of the soil (c and ϕ) and geosynthetic-sand interface (adhesion, c_a and friction angle, δ). The results of direct shear tests included the variation of shear stress–horizontal displacement and vertical displacement–horizontal displacement for sand only and geosynthetic-sand interface at different normal stresses and times elapsed after applying the normal stress.

The variation of shear stress–horizontal displacement and vertical displacement–horizontal displacement for sand alone at the dry density of 1500 kg/m^3 and for σ_n=30 kPa are presented in Figures 3(a) and 3(b), respectively.

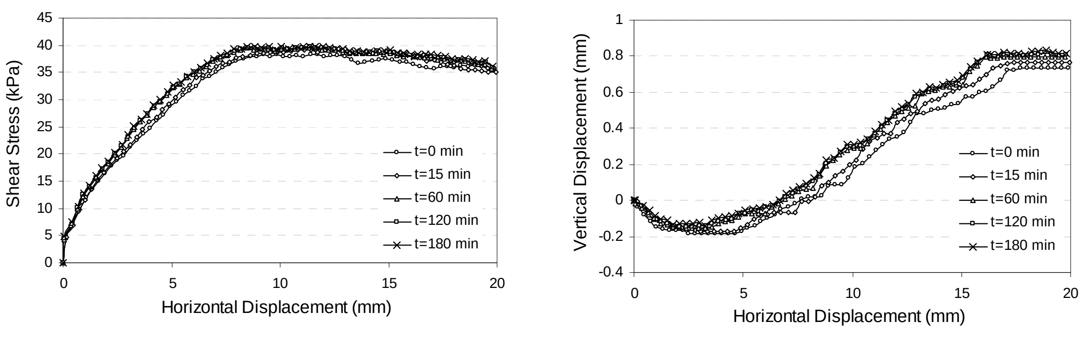


a) Variation of shear stress versus horizontal displacement

b) Variation of vertical displacement versus horizontal displacement

Figure 3. Results of tests for dry sand at different times and for σ_n=30 kPa

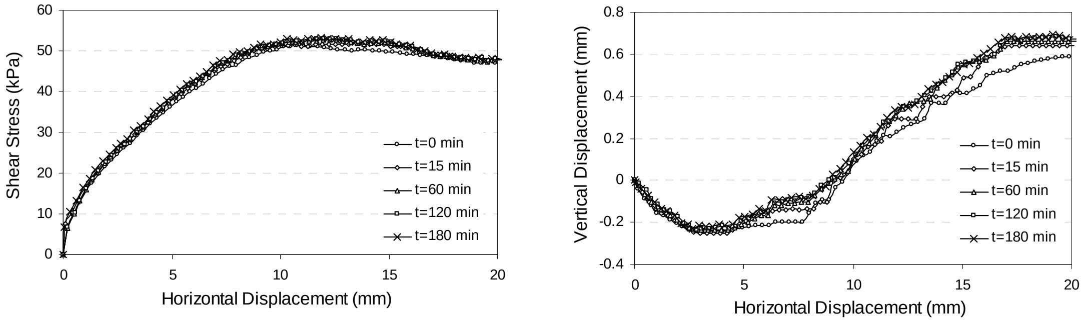
Figures 4 and 5 show results of tests for sand alone under σ_n= 45 kPa and σ_n= 60 kPa for different times, respectively.



a) Variation of shear stress versus horizontal displacement

b) Variation of vertical displacement versus horizontal displacement

Figure 4. Results of tests for dry sand at different times and for σ_n=45 kPa



a) Variation of shear stress versus horizontal displacement

b) Variation of vertical displacement versus horizontal displacement

Figure 5. Results of tests for dry sand at different times and for σ_n=60 kPa

Figure 6 shows shear stress-normal stress variation for dry sand at different times. As seen, the shear stress slightly increases with time.

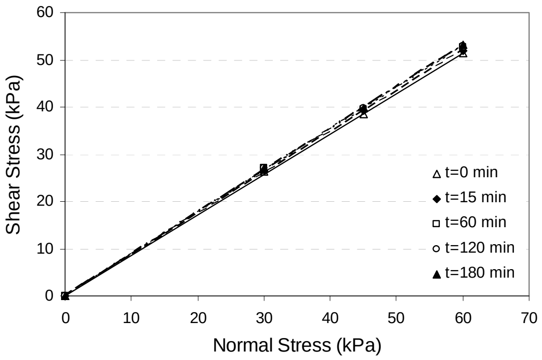
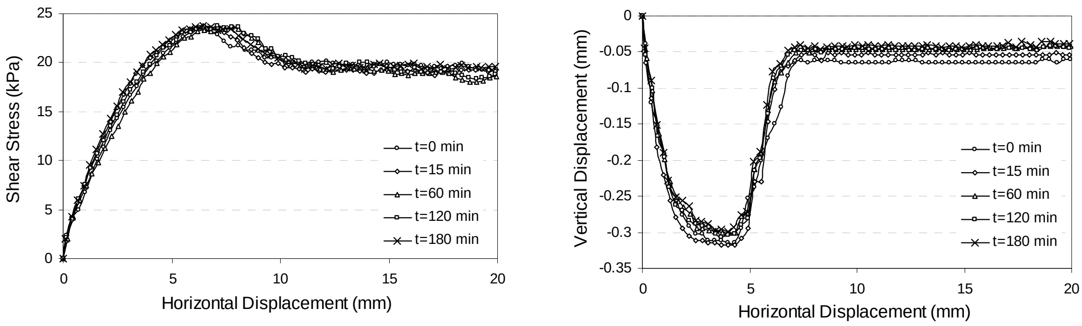


Figure 6. Variation of shear stress versus normal stress for dry sand at different times

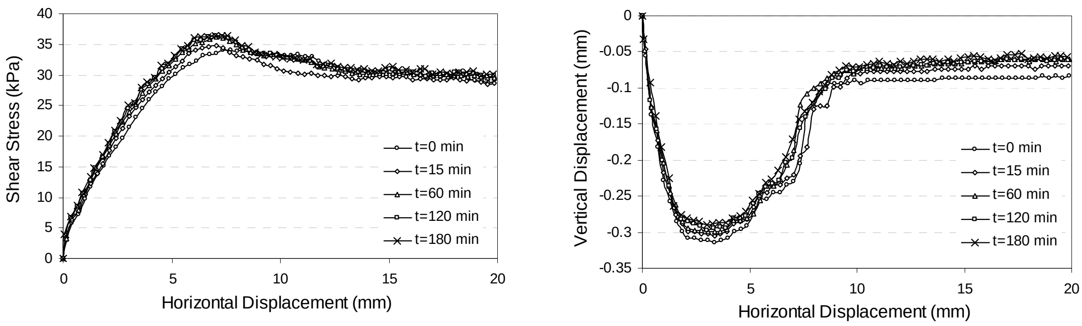
The results of sand–geotextile interface tests for σ_n=30 kPa, σ_n=45 kPa, and σ_n=60 kPa are presented in Figures 7, 8, and 9, respectively.



a) Variation of shear stress versus horizontal displacement

b) Variation of vertical displacement versus horizontal displacement

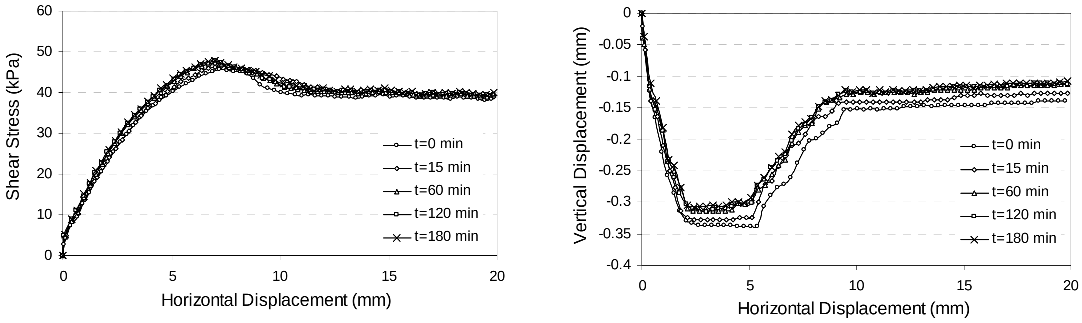
Figure 7. Results of tests for sand-geotextile interface at different times and for σ_n=30 kPa



a) Variation of shear stress versus horizontal displacement

b) Variation of vertical displacement versus horizontal displacement

Figure 8. Results of tests for sand-geotextile interface at different times and for σ_n=45 kPa

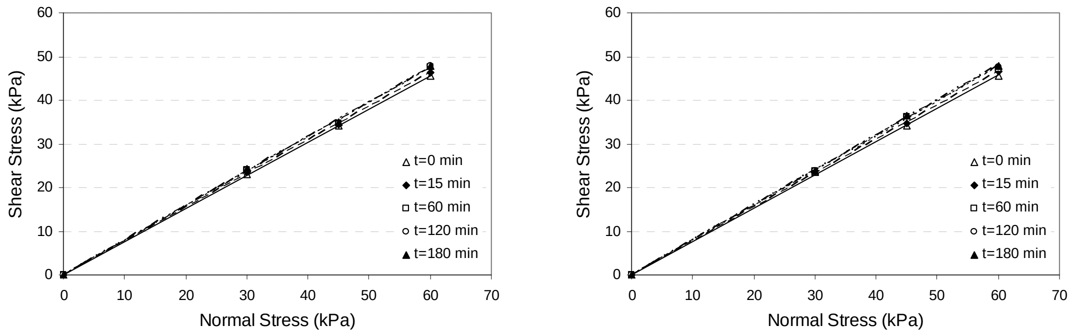


a) Variation of shear stress versus horizontal displacement

b) Variation of vertical displacement versus horizontal displacement

Figure 9. Results of tests for sand-geotextile interface at different times and for σ_n=60 kPa

Figure 10 shows the variation of shear stress-normal stress for dry sand-geotextile at different times. As seen, the shear stress increases with time. Thus accordingly, the friction angle of sand-geotextile slightly interface increases with time.



a) Sand-geotextile GTN.20 interface

b) Sand-geotextile GTN.50 interface

Figure 10. Variation of shear stress versus normal stress for dry sand-geotextile at different times

Friction angle

The values of friction angles of dry sand and sand-geotextile interface at different elapsed times are summarized in Table 3.

Table 3. Values of friction angles of dry sand and sand-geotextile interface at different times

t(minute)	**Sand**	**Sand-geotextile interface**	
		GTN.20	**GTN.50**
0	40.6^o	37.3^o	37.3^o
15	40.9^o	37.7^o	37.9^o
60	41.4^o	38.2^o	38.4^o
120	41.54^o	38.35^o	38.6^o
180	41.57^o	38.4^o	38.65^o

The variation of $\phi_t/\phi_{t=0}$ or $\delta_t/\delta_{t=0}$ with time for only dry sand and dry sand-geotextile interface is presented in Figure 11. As observed, the increase of values of $\phi_t/\phi_{t=0}$ or $\delta_t/\delta_{t=0}$ is significant for first 60 minutes. Beyond this, the variation of $\phi_t/\phi_{t=0}$ or $\delta_t/\delta_{t=0}$ is negligible. Also, the variation of $\delta_t/\delta_{t=0}$ with time for sand-geotextile interfaces are greater than those for the sand alone. As a whole, the value of $\phi_t/\phi_{t=0}$ or $\delta_t/\delta_{t=0}$ increases up to 2.4%, 3% and 3.6% at 180 minutes after the sample is poured in the mold for dry sand and dry sand-geotextile GTN.20 and GTN.50, respectively.

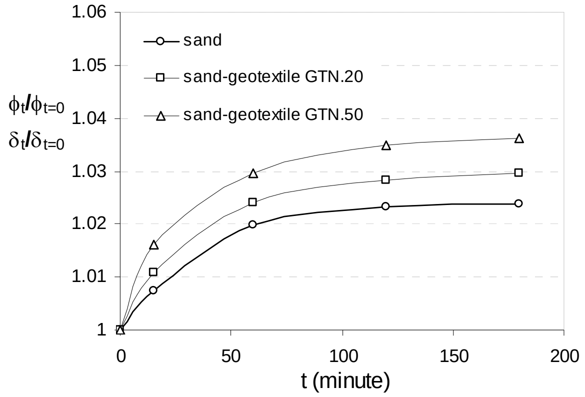


Figure 11. Variations of $\phi_t/\phi_{t=0}$ or $\delta_t/\delta_{t=0}$ with time for dry sand and sand-geotextile interface

Stiffness

For examination of changes of stiffness with time, term k_{50} which is proportional to the stiffness is introduced. This term equals the slope of the line passing through the origin and corresponding to 50% of the maximum shear stress in shear stress-horizontal displacement curve.

The variation of $k_{(50)t}/k_{(50)t=0}$ with time for dry sand and dry sand-geotextile interface is presented in Figure 12. The variation of $k_{(50)t}/k_{(50)t=0}$ with time is as same as the variation of $\phi_t/\phi_{t=0}$ or $\delta_t/\delta_{t=0}$ and those are important for first 60 minutes. As a whole, the value of $k_{(50)t}/k_{(50)t=0}$ increases respectively up to 6%, 10% at 180 minutes after the sample is poured in the mold for dry sand and dry sand-geotextile.

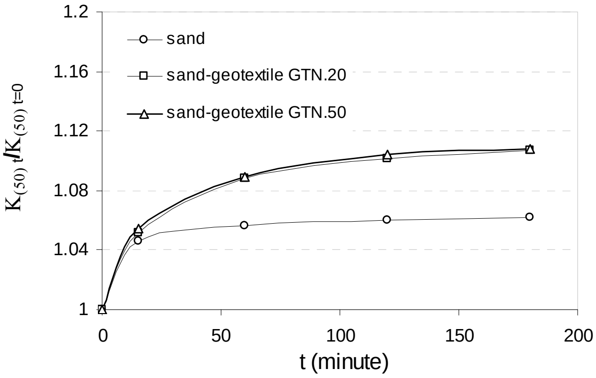


Figure 12. Variations of $k_{(50)t}/k_{(50)t=0}$ with time for dry sand and sand-geotextile interface

DISCUSSION OF RESULTS

Schmertmann (1991) believes that, during aging, small particle movements occur which lead to a more stable soil structure. These movements result in an increase in the stiffness and a decrease in the compressibility of the soil. Mesri et al. (1990) state that the aging effect in sands is due to an increase of frictional resistance that develops during secondary compression. This increasing resistance does not occur solely from the change in the density that occurs during drained secondary compression. Rather, it is due to a continued rearrangement of particles resulting in increased macro interlocking of particles and micro interlocking of the surface roughness. These mechanisms cause an increase in both stiffness and shear stress.

As seen from above figures, the shear strength, friction angle, and stiffness of the sand and sand-geotextile mixture increase with time. However, the rate of increase of these values with time for the sand-geotextile mixture is more than those of the sand alone. This is because in sand-geotextile composite, there are some pores in geotextile and sand grains can enter and move easily inside the pores with time. This leads to a rearrangment and therefore a more stable soil structure.

As seen in Figures 11, when a thick geotextile (GTN.50) is used for sand reinforcement, a greater interface friction angle is obtained compared with the case where thinner geotextile (GTN.20) is used. This is because thicker geotextile layer is more extensible than thinner sheet, leading to greater sand grain movement and thus rearrangement. In addition, the thicker geotextile provides deeper fine voids and thus more sand grains occupy these voids. As a result of these, greater sand movements occur with time.

CONCLUSIONS

Extensive laboratory large scale direct shear tests were performed to evaluate the interface characteristics between sand and two types of geosynthetics within time. For the sand and sand reinforced with geotextile, tests were conducted at a dry density of 1500 kg/m^3. To determine the elapsed time effects on shear strength parameters of the sand and sand-geotextile interface, normal stresses of 30, 45, and 60 kPa were applied at different times of 0, 15, 60, 120, and 180 minutes after the sample is poured in the shear test mold. The effect of thickness of geotextile was also investigated on time-dependent shear strength parameters of the sand and sand-geotextile interface. The results show that the shear strength parameters of sand-geotextile vary with time. Within the scope of this research and the materials used, the results obtained from the tests carried out in this study, the following general remarks may be cited:

- The stiffness and shear strength parameters of sand alone and sand-geotextile interface generally increase with time.
- The compressibility of sand alone and sand-geotextile composite decreases slightly with the elapsed time.
- The increase of friction angle and stiffness with time for sand-geotextile interface is more than those of sand alone.
- Thicker geotextile layers increase the shear strength parameters of sand-geotextile interface more than thiner layers.
- A 3.6% increase in the friction angle and 10% increase in the stiffness of sand reinforced with geotextile GTN.50 were achieved after 180 minutes.

It is generally concluded that the shear strength parameters of sand and sand-geotextile interface increase with time and a variation of shear strength parameters are negligible after of the special of time. In addition, it may be said that, in practice, the strength of sand and sand-geotextile composite is gained soon after the construction stage. It is required to perform further experimental research and field tests to generalize findings in this paper.

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