Measuring Shear Strength of PU Leather-Reinforced Wet Sand

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Abstract. To cope with soil strength problems, reinforcements have been used to improve soil engineering properties. This project uses polyurethane Leather (PU) as a reinforcement material to improve sand strength. Shear strength for reinforced wet sand has been measured and compared with the shear strength in dry condition. The direct shear tests have been conducted to measure the effects of PU leather orientations and quantities on shear strength of wet sand. The triaxial tests have been used to investigate the effects of PU leather contents on shear strength of wet sand as addition tests. Both of test results from either direct shear test or triaxial shear test proved that shear strength in wet sand can be increased due to the reinforcement of soil with PU Leather. Hence, PU Leather is a promising material, which can be used into soil reinforcement to improve the shear strength and other properties of soil.

1. Introduction

Soil reinforcement has aroused widespread concerns and becomes an important aspect of civil engineering. The soil reinforcement technique is used to enhance the engineering properties of the soil by adding external elements into the soil (Kumar, R., Kanaujia, V.K. & Chandra, D., 1999). The ground condition can be improved effectively with the technique of soil reinforcement.

Shear strength, which is the maximum shear stress of resisting shear failure, is one of the most important engineering properties (Sadek, S., Najjar, S.S. & Freiha, F., 2010). The cohesion and the internal angle of friction have been considered as the two significant parameters which can represent the shear strength of soil. According to existing researches that the cohesion and the internal angle of friction were increased with the process of soil reinforcement (Chunling Li, 2005). Shear strength also was increased along with adding external elements into the soil.

When it comes to external elements, it has been found that PU Leather was not in use in any constructions of geotechnical engineering project, hence the engineering properties on this material were not researched. The chemical structure of PU leather can give the polyurethane elasticity as well as tenacity which can influence the soil reinforcement effectively. In addition, PU Leather a biodegradable substance which can be added into soil for soil reinforcement without major environmental pollution issues (Roh, E.K., Oh, K.W. & Kim, S.H., 2013). Therefore, in this project, PU Leather was mixed with wet sand soil and its shear strength was measured.

Based on above literature review, three major research gaps have been found and will require further researches. The first research gap is the quantity of PU Leather in soil. The second research gap is the direction of PU Leather in the process of soil reinforcement. The last research gap is the moisture content that increases shear strength of soil.
In order to solve the research gaps, three aims have been made. The first aim is to determine the quantity of PU Leather and find out which quantity is more effectiveness for soil reinforcement. The second aim is to determine the directions of scarps that has the highest reinforcing effects when being added into ground soil. The last aim is to find out the suitable moisture content which has the largest impact on improving shear strength of soil.

According to aforementioned aims, different sets of tests are performed on different quantities of PU Leather scarps, different directions of PU Leather scarps and different moisture contents of samples. Eventually, the test results are discussed and compared under the principle of control variables.

2. Methodology

2.1 Test samples
In order to adapt to the size of shear box that PU leather was cut into small rectangular pieces with the size of 58mm by 30mm for all scarp quantities and orientation tests. During the cutting, some of the scarps were going to permanently be rolled. However, these effects of permanently rolled of scarps have been considered to have no effects on the curves of graphs as well as performing reinforced scarps into exactly accurate positions.

According to existing researches, the determination of the shear strength of soil can be determined by direct soil shear test and soil triaxial compression test (Abu-Farsakh et al. 2007). In addition, the sand chosen for this project is medium grained sand with the size between 0.22mm to 1.65mm, the average grain size is 0.6mm, which is the same material used in a previous study for consistency in the comparison of the results.

2.2 Direct shear test
Direct shear test was performed in this project to obtain the shear strength properties of wet sand sample with different moisture contents, different quantity of reinforced PU Leather scarps, placed in different orientations. In order to achieve more accurate data, three different axial loads of 50 kPa, 100 kPa and 200 kPa were applied. In addition, three different moisture contents of 2.5%, 7.5% and 10% were tested respectively. The test of direct shear was consisted of three major experiments which were sample of pure sand, sample of one PU Leather scrap and sample of three PU Leather scars. For each of the different samples, the experiment was performed into vertically placed PU Leather scrap, horizontally placed PU Leather scrap and 45 degrees placed PU Leather scrap as shown in Figure 1, under three separate moisture contents in order to investigate the effects of different amounts and different placements of PU Leather on the shear strength of soil.

Figure 1. Different quantities and directions of PU Leather in shear box.

After the preparation of samples and the testing processes, the relevant data includes axial strain, horizontal strain, shear stress and shear strain et.al which can reflect shear strength was achieved directly from GDS direct shear testing machine.

2.3 Triaxial shear test
Triaxial shear test was performed in this project as a supplement method to the direct shear test due to better abilities of controlling conditions of sample drainage and measuring changes of pore water in evaluating shear strength of reinforced soil compared to direct shear test. It can be seen in Figure 2
that the PU Leather was cut into cylinder and mixed with sand along with randomly orientated and distributed. During the test that four different scarp contents which are 0%, 5%, 25% and 50% were performed to investigate the effects of different amount of PU Leather content on the shear strength of soil. All triaxial shear tests were undertaken with three confining pressures which are 50 kPa, 100 kPa and 200 kPa respectively. After the preparation of samples and the testing processes, the relevant data includes axial strain and deviator strain which can reflect shear strength was achieved directly from the machine.

Figure 2. Sample for Triaxial shear test.

2.4 Test matrix
In this project, 54 direct shear tests in Table 1 and 36 triaxial tests in Table 2, have been performed to measure shear strength of wet sand reinforced with PU Leather. It is can be seen in the below tables that all tests with different scrap contents, scarp orientation, moisture contents and axial pressures et.al were presented logically and orderly for measuring shear strength of reinforced soil.

Table 1. Matrix of direct shear test schedule.

| Moisture content (%) | Orientation                                  | Number of Scarp | Axial pressure (kPa) | Tests runs |
|----------------------|----------------------------------------------|-----------------|----------------------|------------|
| 2.5, 7.5, 10         | Sand                                         | 0               | 50, 100, 200         | 9          |
| 2.5, 7.5, 10         | Sand & vertical PU leather scraps            | 1, 3            | 50, 100, 200         | 18         |
| 2.5, 7.5, 10         | Sand and horizontal PU leather scraps        | 1               | 50, 100, 200         | 9          |
| 2.5, 7.5, 10         | Sand and PU leather scraps at 45°            | 1, 3            | 50, 100, 200         | 18         |

Total number of tests: 54

Table 2. Matrix of triaxial shear test schedule.

| Moisture content (%) | PU leather content (%) | Confining pressure (kPa) | Test runs |
|----------------------|------------------------|--------------------------|-----------|
| 2.5                  | 0, 5, 25, 50           | 50, 100, 200             | 12        |
| 7.5                  | 0, 5, 25, 50           | 50, 100, 200             | 12        |
| 10                   | 0, 5, 25, 50           | 50, 100, 200             | 12        |

Total number of tests: 36

All the tests were undertaken with the principle of control variables. It is essential for comparing all results and determining the parameter which will affect the shear strength to a great extent. The changing trends of shear strength, the most suitable PU Leather content and the applied directions of PU Leather scarps can be measured from above direct shear tests and triaxial shear tests. Direct shear
tests were performed to investigate shear strength properties of wet sand sample with different moisture contents, different quantity of reinforced PU Leather scarps, placed in different orientations. Triaxial shear tests were performed as an additional step to assist correctness of direct shear tests to discuss the shear strength of wet sand reinforced with PU Leather.

3. TEST PROCEDURES

3.1 Direct shear test
Direct shear test was performed with three separate stages. The first stage was sample preparation. As it can be seen in Figure 3, the length of PU leather which is 58mm was placed corresponding to the width of shear box. The width of PU leather which is 30mm was placed corresponding to the depth of shear box. At the beginning, some of soil sand was put into shear box before placing PU leather in order to give PU leather a support in case of falling down. Afterwards, PU leather was placed in the central of shear box to achieve the best results of effectiveness from shear strength. When the PU leather was placed in different orientations for different kinds of tests, the sample sand was backfilled until the sand covered PU leather completely. For the test with three PU leather scarps as it shown in Figure 3 that the distances between each scarp was almost 15mm. When conducting 45-degree scarp samples, it was found that 45-degree should be promised between the horizontal surface of sand and the surface of PU leather scarps. All three PU scarps were placed parallel. The second stage was setting of direct shear test machine. To be specific in the second stage, the stage was conducted by maintaining the vertical load constant and shearing the sample in shear box. At the same time, the rate of shear was selected of 1mm/min. The last stage was obtaining the results. As it mentioned above that all relevant data was achieved directly from GDS direct shear machine. The relationships between axial shear and shear strain was plotted to obtain the residual stress. Afterwards, the relationship of axial strain and shear strain was plotted as well.

![Figure 3. Sample with three PU scarps.](image)

With above sections that the values of residual shear stresses and relevant general stresses were chosen to measure the Mohr’s failure envelope, the cohesion and the angle of friction of current sample of reinforced sand which can represent the properties of shear strength of wet sand reinforced with Polyurethane Leather (PU) were measured from Mohr’s failure envelope.

3.2 Triaxial shear test
Triaxial shear test was performed also with three stages. The first stage was the preparation of reinforced sample. As it mentioned before, volumetric method was used to calculate the amount of PU Leather mixed with sand according to the subsequent percentage of reinforcing material. The original size of PU Leather was not feasible because of the size was too big to be compacted into the triaxial sample tube. The scarps of PU Leather were cut into small pieces with the size of 1-2mm in order fit the triaxial sample tube properly. The pieces of PU scarps and medium grained sand were mixed randomly and uniform. The second stage was performing the tests. As mentioned before the triaxial tests were undertaken with different confining pressures as it shown in Figure 4, which was the sample...
pre and post shearing. Compared with above methodology that only 7.5% moisture content samples have been tests for triaxial shear tests because of unavailable testing machines. The third stage was data collecting and these results of data were made and selected to make the relationship curves between deviator and axial strain. The cohesion and the angle of friction of current sample of reinforced sand which can represent the properties of shear strength of wet sand reinforced with PU Leather were measured from Mohr’s failure envelope for triaxial shear test as well.

Figure 4. Sample pre and post shearing.

In addition, in order to make the results more reliable that the effect of evaporation has also been considered. The sample was weighed before and after the triaxial test and it was placed into a dryer to get the dry weight of the sample to measure the loss of moisture content. It was found that the loss of moisture content was within 5% of the expected value before and after the test. When the sample was taken out of the triaxial tube that some lost portion of sample, which can lead to the loss, has been noticed.

4. Results and discussion
Based on the aforementioned aims and research methods, the relationships of shear stress and shear strain, the relationships of axial strain and shear strain, table of residual stress and Mohr’s failure envelope were plotted separately for direct shear tests with every condition which included different moisture contents, different placement of PU Leather scarps, and different number of scarps. It was noting that the different scarp orientations were plotted in one graph in order to find out the difference effects of applying axial loads. For example, taking the sample as one PU scarp with 10% moisture under 100 kPa axial load. The relationships of deviator stress and axial strain, table of angle of frictions were plotted for triaxial shear tests with different contents of PU Leather. Different from direct shear tests that the different confining pressures of 50 kPa, 100 kPa and 200 kPa were plotted in one graph in order to investigate the effects of different pressures to wet sand reinforced samples.

4.1 Direct shear test
To measure the shear strength of reinforced sample with PU Leather, the angle of friction was considered as the most significant parameter which can represent shear strength of soil. Therefore, the overall table of angle of frictions has been made in Table 3 to achieve accurate and more convenient research and analysis between different parameters, which are different moisture contents, different orientations of PU Leather scarps, different scarp numbers, under different applied axial loads.

It was clearly seen from the first line of Table 3 to the last line that the angle of friction had a significant increasing due to adding PU Leather scarps from 0 to 3 scarps. When analysing the soil sample which reinforced with one PU Leather scarp that the increase of shearing strength of the reinforced sample was not obvious enough. Taking the soil sample that had been reinforced with one PU Leather scarp in vertical orientation of 10% moisture content, the increase of angle of friction was six degrees when comparing with non-reinforced sample. That means addition of PU Leather scarps in partially saturated soil sample had some impacts on improving shear strength of sand to some extent.

Regarding to the moisture content, it was found that the moisture content did affect the shear strength to some extent in some cases. As an example, selected the sample of whole 45 degree with
three PU Leather scarps. In Figure 5, the angle of frictions increased a little from 45.16 to 47.19 degree. Furthermore, the highest angle of friction was obtained in completed dry samples which was reinforced with three PU Leather scarps, when comparing the value with 10% moisture content sample which was also reinforced with three PU Leather scarps, the suction factor can be considered as the major cause which affected the angle of friction to a great extent. The addition water can affect the overall shear strength of soil. There is real life situation of soil reinforcement, where the soil was not completely dry at any time, and the above results showed that reinforced soil with PU Leather could work perfectly with some moisture content in it.

Table 3. Angle of frictions calculated for direct shear tests.

| Sample | Moisture content | Orientation | Scrap Number | Angle of friction |
|--------|-----------------|-------------|--------------|------------------|
| Sand   | non             | Non         | 0            | 32.58            |
| Sand   | 2.5             | Non         | 0            | 35.07            |
| Sand   | 7.5             | Non         | 0            | 34.71            |
| Sand   | 10              | Non         | 0            | 41.72            |
| Sand   | 2.5             | Vertical    | 1            | 40.22            |
| Sand   | 2.5             | Horizontal  | 1            | 34.71            |
| Sand   | 2.5             | 45 degree   | 1            | 39.36            |
| Sand   | 7.5             | Vertical    | 1            | 32.62            |
| Sand   | 7.5             | Horizontal  | 1            | 32.00            |
| Sand   | 7.5             | 45 degree   | 1            | 42.49            |
| Sand   | 10              | Vertical    | 1            | 40.22            |
| Sand   | 10              | Horizontal  | 1            | 34.71            |
| Sand   | 10              | 45 degree   | 1            | 39.36            |
| Sand   | 2.5             | Vertical    | 3            | 52.93            |
| Sand   | 2.5             | 45 Degree   | 3            | 45.16            |
| Sand   | 7.5             | Vertical    | 3            | 49.00            |
| Sand   | 7.5             | 45 Degree   | 3            | 45.30            |
| Sand   | 10              | Vertical    | 3            | 53.45            |
| Sand   | 10              | 45 Degree   | 3            | 47.19            |

Figure 5. Angle of frictions with three 45-degree PU scarps of different moisture content.

For example, it was clearly seen in Figure 6 that the increase in shear strength was minor in horizontal orientation compared with other orientations such as vertical or 45 degree and this situation can be attributed to the interface friction soil sand and PU Leather scarps. In fact, the angle of friction will be lower in the sample of horizontal orientation of scarps because the scarps did not affect the soil shear strength. However, the vertical orientation PU Leather scarps which placed in the soil sample
seems had the maximum impact on the shear strength. In most cases in Table 3 that the vertical orientation of scarp has almost the maximum angle of friction and also affects the shear strength of soil sample when compared with other orientations and non-reinforced samples. At the same time, this effect increased along with the increasing number of scarps in same orientation. As an example, the soil sample which was reinforced with three PU Leather scarps as well as 10% moisture content, the increase of shear strength in vertical orientation was up to 18 degrees more than non-reinforced samples. This kind of performance of vertical placement scarps in soil has a promising future for improving shear strength of soil. As for the direction of 45 degree that it also had an impact on increasing shear strength of soil to some extent. Both of the 45-degree reinforced samples had bigger angle of friction when compared with non-reinforced soil samples. In general, the soil samples reinforced with 45-degree scarps had smaller impact on shear strength than the soil samples reinforced with vertical scarps.

![Figure 6. The relationship of shear stress and shear strain with one scarp, 10% moisture content under 200 kPa axial load.](image)

In addition, it can be seen from above results that all compressions of reinforced samples has increased. In addition, this kind of trend existed whether the axial load was increased, or the scarp content was increased. This phenomenon can be attributed to the fact that it was difficult to fill the shear box evenly due to the increasing number of scarps. Also, it was difficult to keep the even fashion of the scarp material, which lead to an uneven distribution of sand and creation of voids eventually. However, the voids were closed up due to the applied axial load on the soil sample.

### 4.2 Triaxial shear test

Triaxial shear test, which as an auxiliary method, was applied to prove the effects of shear strength of wet sand reinforced with PU Leather. Similar to the direct shear test that the overall table of angle of frictions and cohesions was made in Table 4 to show the relations between different scarp contents or moisture content and angle of frictions. At the same time, the overall table of deviator stress was shown in Table 5.

| Sample                                      | Angle of friction | Cohesion |
|----------------------------------------------|-------------------|----------|
| Pure sand (Dry)                              | 31°               | 0        |
| Pure sand (7.5% MC)                          | 29°               | 0        |
| Sand (5% PU leather) (7.5% MC)               | 31.5°             | 5        |
| Sand (25% PU leather) (Dry)                  | 33°               | 10       |
| Sand (25% PU leather) (7.5% MC)              | 35°               | 18       |
| Sand (50% PU leather) (7.5% MC)              | 38°               | 38       |
Table 5. Summary of angle of frictions and deviator stresses at 10% Axial strain, 200kPa confining pressure.

| Sample                                           | Angle of friction | Deviator stress |
|--------------------------------------------------|-------------------|-----------------|
| Pure sand (Dry)                                  | 31°               | 555.13          |
| Pure sand (7.5% MC)                              | 29°               | 405.11          |
| Sand (5% PU leather) (7.5% MC)                   | 31.5°             | 465.72          |
| Sand (25% PU leather) (Dry)                      | 33°               | 679.74          |
| Sand (25% PU leather) (7.5% MC)                  | 35°               | 771.81          |
| Sand (50% PU leather) (7.5% MC)                  | 38°               | 761.73          |

It was clear that PU Leather scarps had a positive impact on the properties of shear strength of soil sample as it can be seen from the increasing angle of frictions along with the increased of PU Leather content. At the same time, the cohesion also increased with the increased of PU Leather content in soil sample.

As seen in Table 5 that the angle of frictions and cohesions of the soil sample were increased with the increases PU Leather content in soil sample. Above phenomenon was more obvious when under the 200 kPa confining pressure just as Figure 7. This kind of phenomenon can be attributed to the increased shear strength of the soil sample. In addition, the results which were calculated from the Mohr coulomb model along with the shear strain relationship for every soil sample showed that the PU Leather scarps are reinforcing the soil sample, the best results obtained was from 25% of PU Leather scarps.

Figure 7. The relationship of deviator stress and axial strain with 200 kPa confining pressure.

In conclusion after refining the results obtained from the triaxial shear tests that the PU Leather has been proved to strengthen the shear strength of soil sand to a great extent. With the increased percentage of the PU Leather in the soil sample, it was noted that the angle of frictions also increased. For soil samples which contained 100% PU Leather, the angle of frictions cannot be increased due to the difficulties of preparing of compacting PU Leather. So, the test was limited to 50% PU Leather and 50% sand sample.

5. Conclusions

This paper focuses on measuring shear strength of wet sand reinforced with PU Leather. In order to achieve established goals that two main tests were conducted, which were direct shear test and triaxial shear test, to gain the relevant data in order to fully understand the changes, which were caused by adding external material, of shear strength in sand samples. Direct shear tests were performed under different axial loads with different moisture contents, scarps orientations and scarps numbers. Triaxial shear tests were performed with different scarp contents along with different axial confining pressures. Both of test results from either direct shear test or triaxial shear test proved that shear strength in wet
sand can be increased due to the reinforcement of soil with PU Leather. To be specific, the increased content of PU Leather can increase shear strength to some extent. Three scarps of PU Leather had better performance on improving shear strength in this project when compared with one scarp or non-scarps. The moisture content of sand can be considered as a significant parameter which can affect the shear strength of wet sand to some extent. The vertical placement scarps in wet sand had the highest reinforcement effects of shear strength among current horizontal or 45-degree scarps.

The results above showed that PU Leather, as an effective material, which can be used into soil reinforcement to improve the shear strength and other properties of soil, has a promising future. In the meantime, PU Leather is a biodegradable material which can be deposited quickly without too much environmental problems (Sudha et al. 2009). Both of above advantages of PU Leather can prove that PU Leather is suitable for soil reinforcement in civil engineering careers.

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References
[1] Abu-Farsakh, M., Coronel, J. and Tao, M., 2007. Effect of soil moisture content and dry density on cohesive soil–geosynthetic interactions using large direct shear tests. Journal of Materials in Civil Engineering, 19(7), pp.540-549.
[2] Cetin, H., Fener, M. and Gunaydin, O., 2006. Geotechnical properties of tire-cohesive clayey soil mixtures as a fill material. Engineering geology, 88(1-2), pp.110-120.
[3] Chunling Li, 2005. Mechanical response of fibre-reinforced soil.
[4] Edil, T.B. and Bosscher, P.J., 1994. Engineering properties of tire chips and soil mixtures. Geotechnical testing journal, 17(4), pp.453-464.
[5] Fern, J., Soga, K. and Robert, D.J., 2014. Shear strength and dilatancy of partially saturated sand in direct shear tests. In Proc., TC105 ISSMGE Int. Symp. on Geomechanics from Micro to Macro, Taylor & Francis, London (pp. 1391-1396).
[6] Kumar, R., Kanaujia, V.K. and Chandra, D., 1999. Engineering behaviour of fibre-reinforced pond ash and silty sand. Geosynthetics International, 6(6), pp.509-518.
[7] Roh, E.K., Oh, K.W. and Kim, S.H., 2013. Classification of synthetic polyurethane leather by mechanical properties according to consumers’ preference for fashion items. Fibers and polymers, 14(10), pp.1731-1738.
[8] Sudha, T.B., Thanikaivelan, P., Aaron, K.P., Krishnaraj, K. and Chandrasekaran, B., 2009. Comfort, chemical, mechanical, and structural properties of natural and synthetic leathers used for apparel. Journal of Applied Polymer Science, 114(3), pp.1761-1767.
[9] Sadek, S., Najjar, S.S. and Freiha, F., 2010. Shear strength of fiber-reinforced sands. Journal of geotechnical and geoenvironmental engineering, 136(3), pp.490-499.