Reinforcement of sandy soil using plastic fibres made from waste plastic bottles

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Abstract

Today waste plastic bottles are spread widely throughout our world especially in Kurdistan, an autonomous region in Iraq. These waste products cause many environmental problems and at the same time some soils are weak and need reinforcement using cheap materials such as Polyethylene terephthalate (PET) waste plastic bottle. Use of waste plastic bottles as a reinforcement of soil is highly recommended to reduce the amounts of plastic waste, which creates a disposal problem. In this study an attempt was made to use plastic fibres produced from waste bottles to reinforce sandy soil. This can solve both environmental and geotechnical problems. In the research, the effect of plastic fibres content as well as fibre length on shear strength parameters (cohesion and internal friction) were experimentally predicted using the direct shear test method so as to improve bearing capacity of weak soils. The results showed that under low normal stress the inclusion of plastic fibres increased both angle of internal friction and cohesion; however, under high normal stress (greater than 100 kPa) the cohesion increased and the internal friction was roughly unchanged. Also, it was concluded in this study that the suitable amount of fibers that can be added to weak soils is 1% of dry weight of sand.

Key words: Direct shear test, Post-failure, Reinforced sand, Plastic fibres.

تقوية الترب الرملية باستعمال الألياف البلاستيكية المأخوذة من فضلات القناني البلاستيكية

يونس مصطفى علي الشكاني

الخلاصة

لقد أصبح في الوقت الحاضر استعمال القناني البلاستيكية منتشرا في العالم وخاصة في إقليم كردستان التي تعد منطقة حكم ذاتي في العراق. إن انتشار هذه الفضلات تتسبب بمشاكل بيئية لذا يمكن الاستفادة من هذه الفضلات البلاستيكية في تقوية الترب الضعيفة لتقليل كميات الفضلات الناتجة من القناني البلاستيكية. تم في هذه الدراسة استعمال ألياف البلاستك من القناني البلاستيكية لتقوية الترب الرملية والتي سوف تحل مشاكل التربة والبيئة. تم دراسة تأثير محتوى الألياف وطول الألياف على مقاومة القص (التماسك والاحتكاك الداخلي) مختبريا باستعمال تجربة القص المباشر لتحسين قوة تحمل الترب الضعيفة. بينت النتائج أن الألياف البلاستيكية تحت تأثير الإجهادات الواطئة تزيد كل من قوة تماسك والاحتكاك الداخلي للتربة بينما عند الإجهادات العالية أكثر من 100 كيلو باسكال تزداد التماسك بينما لا تتغير الاحتكاك الداخلي التربة. كما تم الاستنتاج من الدراسة أن أنسب كمية من الألياف البلاستيكية هي 1%من وزن الالياف.

1. Introduction

Waste plastic bottles are spread widely in our world particularly in Kurdistan region of Iraq because the waste plastics are not recycled. These cause many environmental problems while on the other hand some soils are weak and need reinforcement using cheap materials such as such as Polyethylene terephthalate (PET) waste plastic bottle. Over the past four decades, economic and environmental issues have stimulated interest in the development of alternative materials that can satisfy design specifications [1]. Use of waste plastic bottles as a reinforcement of soil is highly recommended to reduce the amount of plastic waste, which creates a disposal problem. Fibres can be made from these waste plastic bottles which then can be used to reinforce weak soil. Produced

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fibres can be mixed either systematically with soils or randomly. Randomly distributed fiber-reinforced soils exhibit some advantages. Preparation of randomly distributed fiber-reinforced soils mimics soil stabilization by admixture. Discrete fibres are simply added and mixed with the soils, much like, lime, cement. Randomly distributed fibers offer strength isotropy and limit potential planes of weakness that can develop parallel to oriented reinforcement [2].

In the past few decades several studies have been conducted on randomly distributed fiber-reinforced. (e.g., [2,3,4,5,6,7,8,9,10]). These studies showed that stress strain– strength properties of randomly distributed fiber-reinforced soils are governed by fiber content, aspect ratio and fiber-surface friction along with the soil and fiber index and strength characteristics. Also, they reported that fibre reinforcement can be used to increase the peak strength as well as residual strength. However, there is not enough information about the effect of long and short fibres on the Mohr-Coulomb failure envelope under low normal stress using a direct shear test. Gray and Maher [6] reported that poorly graded sand reinforced with fibre showed curvilinear failure envelope whereas well-graded sand samples showed bilinear failure envelope. Ranjan et al [7] studied the behaviour of sand reinforced with discrete randomly distributed fibres using a triaxial compression test. Their results showed that sand-fibre composites have a curved or a bilinear failure envelope, with the break occurring at a certain confining stress, called the ‘critical confining stress’. However, in this study it will be shown that this bilinear failure envelope is not only related to the fibre content but most of materials exhibit a bilinear failure envelope especially soils. It should be noted that Hejazi et al [11] made a review about soil reinforcement by using natural and synthetic fibers and they concluded that ‘’the actual behavior of fiber reinforced soils is not yet well-known’’; therefore, more studies in this field are highly required especially the behaviour of cohesion-less soils under direct shear test.

This research presents results on the engineering behaviour of sand reinforced with waste plastic material. The main objective of the study was to determine the effect of fiber reinforcement on the shear strength envelope of sand. Furthermore, the effect of fibre length and plastic content on shear strength and shear stress-horizontal displacement was investigated. A series of direct shear tests were conducted to investigate the effect of fiber content made from waste plastic on the behavior of sand under low and high normal stresses. The results obtained from the tests are presented and then discussed.

2. Methodology

2.1 Direct shear test

The direct shear box apparatus (Wykeham Farrance model 27 WF2160) shown in Figure 1 is normally used for testing unreinforced and reinforced sand. The test equipment consists of a metal box which is split into an upper and lower half and into which two samples (upper and lower) are placed. Normal stress is applied to the upper surface of the upper sample using a dead load and a hanger. The test was conducted according to ASTM- D-3080.

Shear stress is applied along the lower part of the shear box by moving the bottom half of the box with a displacement rate of 0.5 mm/min relative to the top (ASTM- D-3080).

Figure 1. Direct shear box apparatus

2.2 Materials

2.2.1 Sand

Sandy soil was selected to carry out the experimental study. The sand was collected from alluvium in Sirwan River in northern part of Iraq.

The oven dried sand passing through sieve no.4 (4.75 mm) which is the fraction of the material that was selected for subsequent investigation. The grain size distribution is shown in Figure 2.

Table 1. presents the index properties of the sandy soil.

Characteristic	**Value**	
Minimum density ρ_{min}	1.520 gr/cm^3	ASTM D 4254
Maximum density ρ_{max}	1.740 gr/cm^3	ASTM D 4253
Molding dry density ρ_d	1.612 gr/cm^3	ASTM D 4254
Specific Gravity, G_s	2.65	ASTM D854
Effective grain size (D_{10})	0.24 mm	ASTM D 2487 The Sand was classified according to the Unified Soil Classification System (USCS).
Gradation coefficient (C_c)	0.7	
Uniformity Coefficient (C_u)	5.8	
Sand Type	SP (Poorly graded Sand)	

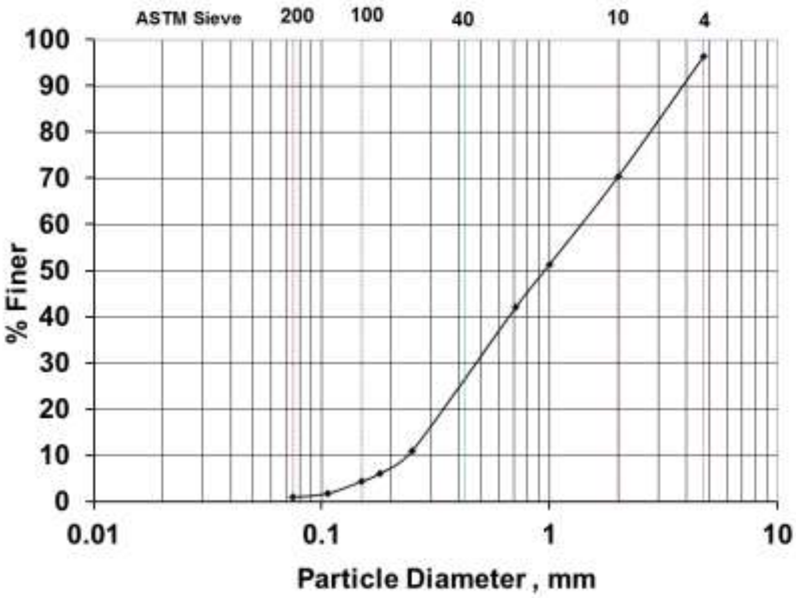

Figure 2. Grain size distributions of sandy soil (Cc=0.7 and Cc=5.8)

2.2.2 PET-Fibres

For the improvement of engineering properties of soil, Polyethylene terephthalate (PET) waste plastic bottle fibers were used as reinforcement. These PET waste plastic bottle fibers have been used in two different types which they are long (denote as L) and short (denoted as S) fibres. These two types of plastic fibres were used with local natural sand in three different percentages of 1%, 2%, and 4.0% by dry weight of sand. Waste plastic bottles are generally comprised of polyethylene. Figure 3 shows the plastic fibres that were cut from waste plastic bottles.

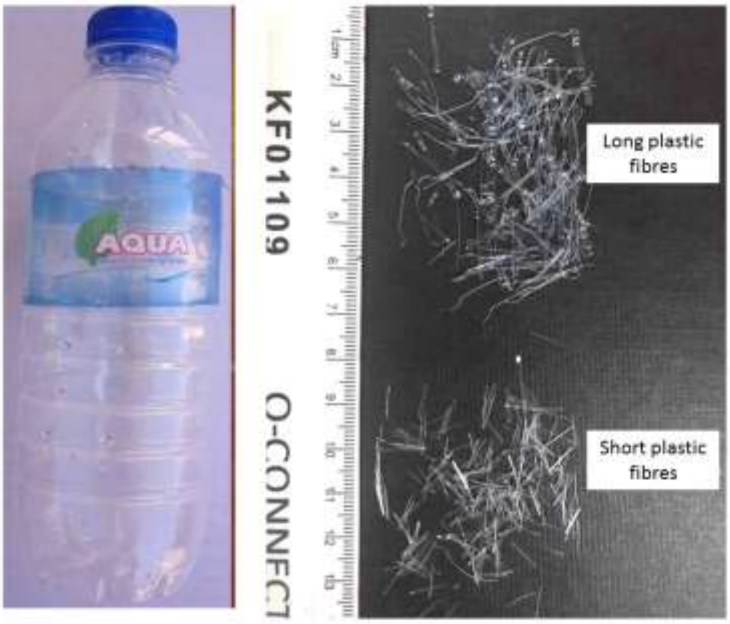

Figure 3. Fibres made from waste plastic bottles (PET)

2.3 Sample Preparations

The fibers were cut into lengths of 16 mm for long fibres and 8 mm for short fibres. Local sand was collected and then was oven dried. The plastic fibers were added with sand at three different percentages 1, 2, and 4%. Plastic fibers have been added to sand under dry conditions and mixed mechanically using the cultivated method. The mix thus obtained was used for preparation of direct shear test specimens. The tests were conducted on both unreinforced and reinforced sand specimens so as to compare between shear strength characteristics of unreinforced sand with that of reinforced sand by varying the fiber content and fiber length. A special rod was used to compact the samples.

3.Results and discussion

Figures (4-7) show the shear stress-strain relationships for unreinforced and reinforced sand with long fibres (16mm). These Figures show that the peak stress increases with increasing the percentage of plastic fibres. Also, the post failure strength increases as the fibres content increases. Furthermore, the post-failure behaviour is improved significantly.

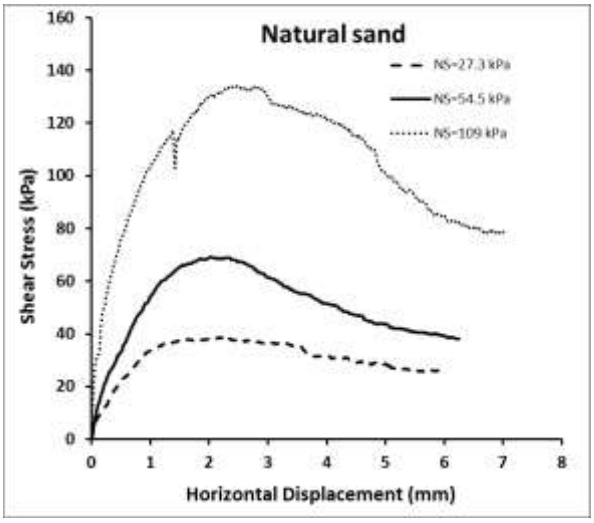

Figure 4. Shear stress–horizontal displacement response for unreinforced sand, (note: NS denoted for normal stress).

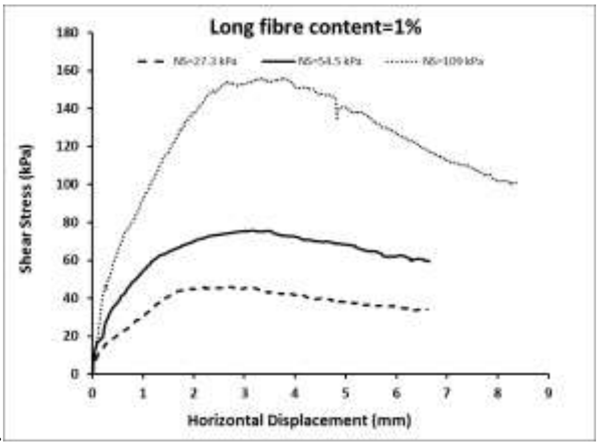

Figure 5. Shear stress–horizontal displacement response for sand reinforced **with long fiber** content of 1%.

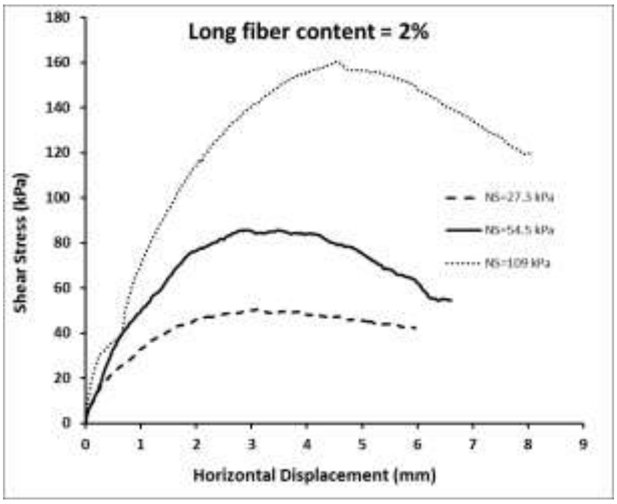

Figure 6. Shear stress–**horizontal displacement response for sand reinforced with long fiber** content of 2%.

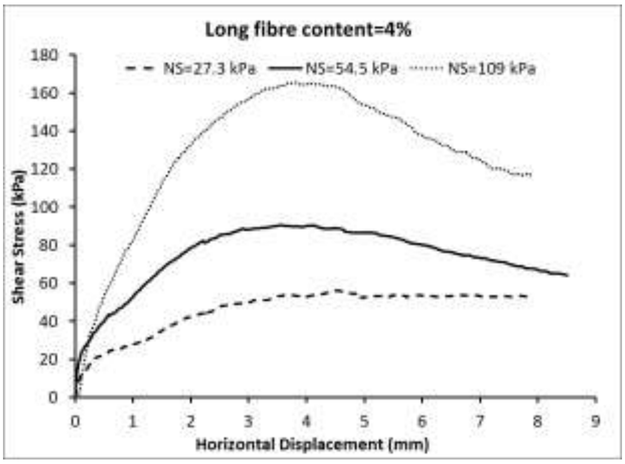

Figure 7. Shear stress–horizontal displacement response for sand reinforced with long fiber content of 4%.

Figure 8 shows the Mohr-Coulomb failure envelopes for unreinforced and reinforced sand with different percentages of plastic fibres. As can be seen from figure 8, a percentage mix of plastic fibre above 1% improves strength marginally for sandy soils; whereas a fixed percentage of 1% shows extremely promising results with a significant improvement in overall strength. From these findings, it can be concluded that the best percentage of PET fibres that should be added to sandy soils is 1%.

Furthermore, the cohesion increased significantly when sand was reinforced with fibres. It may be concluded that the role of fibre plastics is to reinforce the sand-fibre mixture bonds that contribute to the cohesion of sand under normal stress or confining stress. Also, Figure 8 shows the coefficient of determination (R^2), as can be seen the value of the coefficient is almost equal to 1, thereby confirming the accuracy of the analysis presented in this study.

To study the bilinear behaviour of the failure envelope more tests must be done under low and high normal stresses as presented in section 3.2.

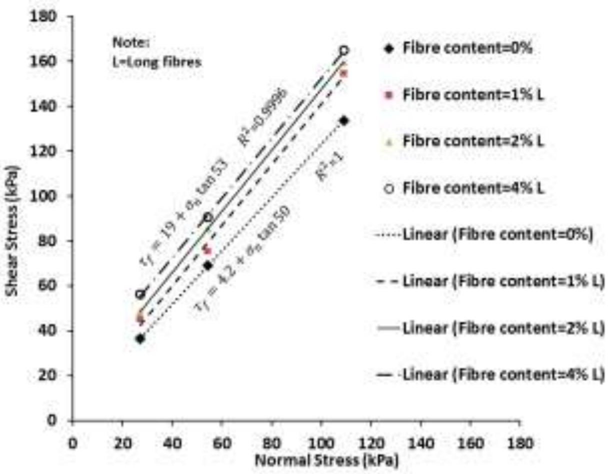

Figure 8. Mohr-Coulomb failure envelopes for long fiber reinforced and unreinforced sand samples.

Figure 9 shows the shear stress-horizontal stress relationships of reinforced sand with short fibres of 8 mm length. When comparing with a similar percent of long fibres (see Figure 6), it can be concluded that the peak strength is roughly same in the case of both long and short fibres. However, the similar percentage of short fibres exhibits less ductility than long fibres. However, the strength parameters stay roughly same (see Figure 10) but the strength of sand reinforced with short plastic is slightly higher than long fibres for similar percentage of plastic fibres. Therefore, we can conclude that the short fibres are better than long fibres.

Figures (11 and 12) show the effect of short and long fibre content on the shape of shear stress-horizontal displacement relations for different percentages of plastic fibres (0%, 1%, 2% and 4%) under normal stress of 54.5 kPa. As can be seen that the shape of the curves are roughly similar until shear displacement of 1.5 mm and there is no any effect of the plastic fibres. However, the effect of fibres develops when the horizontal displacement is more than 1.5 mm in the direct shear test of cohesion-less materials. This is because the friction between fibres and sand was mobilized when horizontal displacement is about 1.5 mm.

Once again the inclusion of short fibres shows less ductility than long fibres at the same percentage of fibre plastics under constant normal stress.

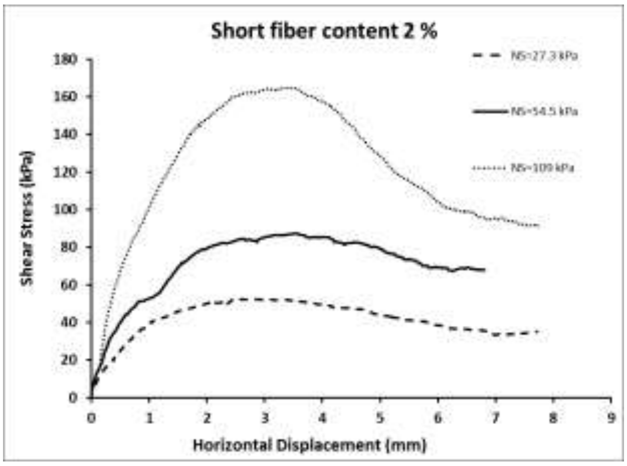

Figure 9. Shear stress–**horizontal displacement response for sand reinforced with short fiber** content of 2%.

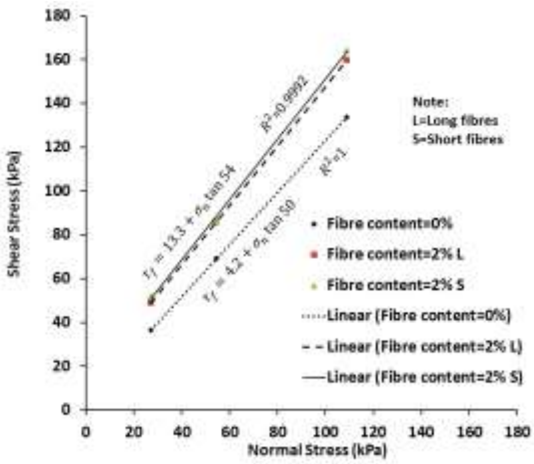

Figure 10. Mohr-Coulomb failure envelopes for short and long fibers reinforced and unreinforced sand samples.

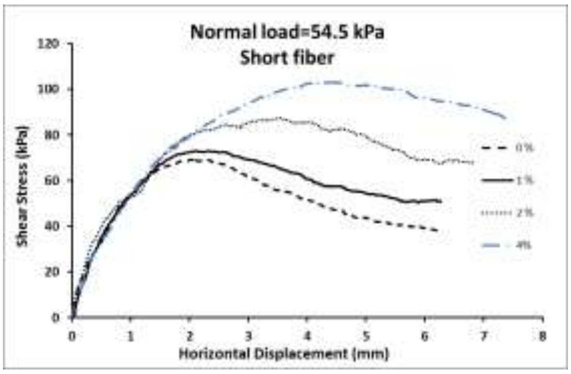

Figure 11. Shear stress–horizontal displacement response for unreinforced sand and sand **reinforced with long fiber content.**

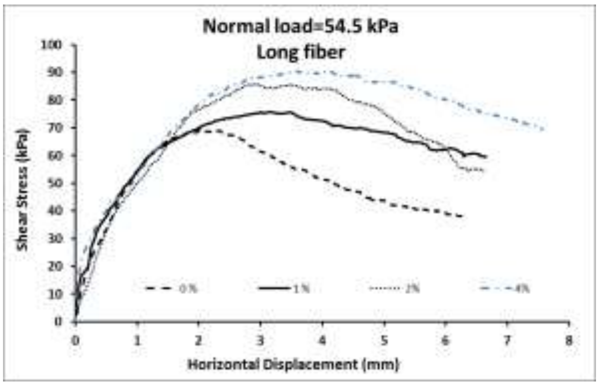

Figure 12. Shear stress–horizontal displacement response for unreinforced sand and sand **reinforced with short fiber content.**

Figure 13 shows the Mohr-Coulomb failure envelops for unreinforced sand and reinforced sand with 2% of long fibres which was predicted using a series of normal stresses so as to study the behaviour of the Mohr-Coulomb failure envelope under high normal stress. We can conclude that not only the reinforced sand exhibit the bilinear failure envelope as reported in the literature; but the unreinforced sand exhibits a similar behavior as well. These results also show that the break in the failure envelope occurs at a normal stress of 110 kPa.

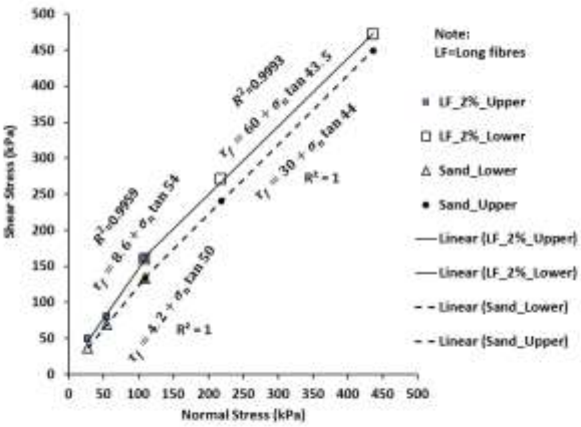

Figure 13. Mohr-Coulomb failure envelopes for long fiber reinforced and unreinforced sand samples.

Nasif [20] showed that the inclusion of plastic pieces to sandy soils did not increase the cohesion of soils significantly but the angle of internal friction increased considerably with inclusion of different percentages of plastic pieces for sandy soils. However, reinforcement of sand should increase the cohesion of sand significantly and not the angle of internal friction. In this study, the effect of inclusion of plastic fibres on strength parameters (cohesion and angle of internal friction) was studied for long fibers under low and high normal stresses. Figure 14 shows the relationship of plastic fibres content versus cohesion, as can be seen that this parameter increases slightly with increasing the percentage of plastic fibres under low normal stress (less than 110 kPa) and increases significantly when the normal stress is greater than 110 kPa. However, increasing the percentage of plastic fibres has almost an unimportant effect on angle of internal friction under low normal stress (less than 110 kPa), whereas increasing the normal stress beyond 110 kPa the angle of internal friction changes from 54 degrees to about 44 degrees because under high normal stress the effect of angle of dilation is reduced.

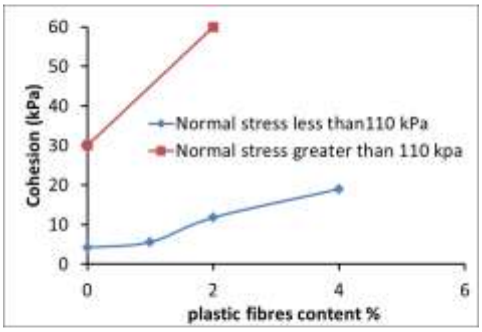

Figure 14. Effect of plastic fibres content on cohesion.

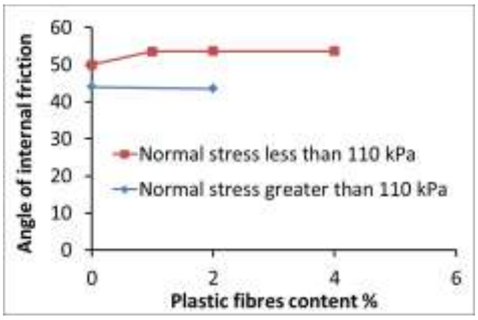

Figure 15. Effect of plastic fibres content on angle of internal friction

Noorzad and Zarinkolaei [21] studied reinforced sand with polypropylene fibres using both Triaxial and Direct Shear Tests. They reported that the Mohr-Coulomb failure criterion was linear using both methods. Similar results were reported by Yetimoglu and Salbas [2] when they studied the shear strength behaviour of sands reinforced with randomly distributed discrete fibers using direct shear tests. However, in this study, it was concluded that the Mohr-Coulomb failure envelope is bilinear for both reinforced and unreinforced sand.

4.Conclusions

The effect of reinforced sand with PET fibres on strength properties was systematically investigated in this study using two types of fibres which are long fibres of 16 mm and short fibres of 8 mm. Three percentages of fibres were used as: 1, 2%, and 4% by weight of dry sand. The results showed that the short fibres gave less ductility than long fibres with the same amount of plastic-fibres but gave similar results of peak stresses. Furthermore, both unreinforced and reinforced sand showed a bilinear failure envelope that has a break at a certain level of normal stress. Under low normal stress the inclusion of plastic fibres increased both angle of internal friction and cohesion; however, under high normal stress (greater than 100 kPa) the cohesion increased and the internal friction was roughly unchanged. Also, it was concluded in this study that the suitable amount of fibers that can be added to weak soils is 1% of dry weight of soils. Therefore, we conclude that the fibres made from waste plastic bottles can be successfully used to enhance the strength of soil material.

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