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Soil Reinforcement with Synthetic Fibers and Plastic Waste Materials: A Review

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ABSTRACT

The soil reinforcement technique is used to improve the engineering characteristics of soils. In this technique, various types of reinforcement elements have been used in constructions for a very long time. As mentioned in the previous literature, the use of synthetic fibers and plastic waste materials has shown promising results. when these fibers inclusion in soils, significant enhancements are demonstrated in the overall mechanical properties (especially strength properties) of reinforced soils. Sequentially, the randomly distributing methods of fibers have involved increasing attention in geotechnical applications due to its efficiency in improving soil properties. In this study, the soil-reinforcement mechanism, types of fibers (synthetic and plastic waste material), and applications of these fibers in various types of constructions were reviewed. The advantages and disadvantages of synthetic and plastic waste material fibers were also discussed. As well, some recommendations were also mentioned in this review paper in order to fully understand the behavior of reinforced soils if these recommendations were taken into account.

Keywords:

Soil stabilization; synthetic fibers; plastic waste; resistance properties; engineering applications.

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1. INTRODUCTION

In many countries of the world, engineers use different types of materials in the constructions [1]. Among these materials, earth materials have been used in structural projects, and stay to be used in present times [2]. Further, fibers have been also used in construction [3, 4]. Historically, composite materials have been used in different buildings, in which fibers were used in these buildings as reinforcement elements. Fibers were used in earlier civilizations such as Babylon, Egyptian, Chinese and Japanese civilizations [3]. Recently, more attention has been done to the use of fibers within the soils, to enhance their engineering properties. However, fiber insertion in soils brings many technical, economic and environmental benefits [5-7].

[8] investigated the triaxial compression shear strength of silty sand soil mixed with different percents of palm fibers. The results showed that, the reinforced soil samples exhibited approximately 25% increase in friction angle and 35% in cohesion as compared to those of unreinforced samples. Literature review that has been accomplished by some previous authors in their relevant research to those of unreinforced samples.[9] reported that the inclusion of 1% fiber in sand stabilized with cement increased the unconfined compressive strength. Moreover,[10] found that the addition of polypropylene fibers enhanced both the unconfined compressive and tensile strengths of reinforced clay soil.[11] studied the CBR of two soils reinforced by kenaf fibers. The results showed that the CBR values improved with fiber addition. The improvement in the strength related to that, during loading, the forces acting on soil grains lead to activating the strength in the fibers (i.e. tensile resistance) [12, 13]

In general, fibers are found in huge quantities in natural, synthetic and waste forms. All these types of fibers are used in civil engineering constructions [14-18]]19[. Fig.1 illustrates different types of fibers which can be used to enhance the geotechnical properties of soils, and some of them are reviewed in this paper.

1.1 Method of collecting papers.

This paper is a review paper thus, the main work is to collect literature reviews and different papers speaking about synthetic fibers and plastic waste materials and their use as construction materials. Date publication of the collected articles varied from 2000 to 2022. The selected papers included the papers that had been concentrating on using fibers in geotechnical engineering only. To achieve the goal of this review, more than 80 different papers were studied. Finally, the selected papers are mostly peer-reviewed papers obtained from numerous journals.

1.2 Objective

The main objective of this paper is to review the mechanism of soil reinforcement, the types and properties of synthetic fibers and plastic waste materials which used in geotechnical engineering applications. Moreover, the advantages and disadvantages of these types of fibers are reviewed and discussed. Test results of prior studies that successfully tried to utilize these types of fibers in geotechnical applications are then reviewed. Finally, some recommendations for further research works are suggested.

2. SOIL REINFORCEMENT

Soils in nature are strong in compression and can resist most applied loads, but they are weak in tension [10]. In most construction applications, soil properties can be enhanced by various techniques [12, 20-22]. Among these techniques, is the soil reinforcement. Generally, reinforcement means the insertion of certain materials having a good tensile strength within the soils that are absent of this property (i.e., tensile strength). [11]. Different kinds and forms of reinforcement elements are used to enhance the engineering characteristics of soils (like strength,
compressibility, etc.), leading to a new material, named the reinforced soil [3, 4, 11, 23, 24].

Soil reinforcement is not a new method in civil engineering applications. The ancient Ziggurat (see Fig.2) found in Iraq, is an excellent example of soil reinforcement application. Moreover, the soil reinforcement technique can be noticed in nature. It can be observed that the natural fibers of different sizes (roots of plants) stabilize the soil in sloping and level ground [11]. With knowledge of the role of roots to reinforce soils, the concept of fiber reinforcement come to be important in civil engineering applications.

Fig. 1 Pictures show some types of fibers

The soil reinforcement with roots can be artificially replicated by the insertion of various kinds of fibers within the soil (natural and synthetic fibers). Plastic waste materials can also be used as fibers to reinforce the soil [25-27].

In laboratory and field works, fibers are mixed with soil in a random state. Random state means the soil and fibers were mixed thoroughly and randomly in a dry state. The benefit of using the randomly distributed method of fibers is that this method limits the potential planes of weakness (between soil and fiber) that may create oriented-to-parallel reinforcement [12, 28, 29]. Many research papers (especially the papers mentioned in this review paper) have presented that the use of fibers (even waste fibers) causes significant improvement in the engineering characteristics of soils (especially strength characteristics).

Moreover, these papers referred that reinforced samples exhibit lesser loss of post-peak strength and higher extensibility more than the unreinforced samples. This behavior is attributed to the fiber-reinforced soil being more ductile. It is worth noting that, the fiber-reinforced soil is a composite material and its behavior mainly depends on both behaviors of soil, fiber and the interface between them [1, 13, 30-32] [33]. The addition of fibers to the soil enhances its stress-strain behavior by mechanically cooperating with the soil grains by interlocking, bonding and friction [34]. The interlocking causes a load to transfer from the soil particles to the fiber by activating the tensile stress of the fiber itself and this mechanism is presented in Fig.3. Also, this figure illustrates that, during loading, the applied stress on the soil grains causes fiber deformation. During fiber deformation, the tensile resistance will be activated in the fiber itself and consequently imparts more strength to the soil-fiber composite system.

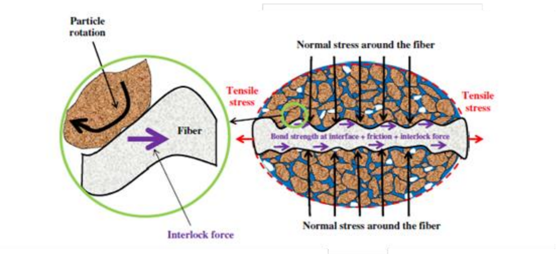

Fig.2 Ziggurat of Ur in Iraq

Fig.3 Mechanism of grain rotation that induces interlock and friction in fiber [29]

3. TYPES OF FIBERS

Fiber is a unit of the material described by fineness, elasticity and a large aspect ratio (the ratio of length to diameter or thickness). Moreover, fiber is a type of material that are continuous filaments or are in separate pieces, like lengths of thread [11]. Human uses for fibers are varied. They can be used in civil construction applications and industry. Fibers are got from natural, synthetic and waste materials. For waste materials, only non-hazardous type is used.

Natural fibers represent those fibers produced by plants and they are characterized by their low cost, acceptable tensile strength, bulk availability and environmentally friendly characteristics. The only practical drawback of natural fibers is biodegradability with time and they have poor durability [32, 35]. Natural fibers can be used as unconventional low-cost reinforcing elements for enhancing the engineering properties of soils. They can be used in several applications, like the construction of roads for villages, forest areas and other environmentally friendly applications [12, 36-38] It is worth noting that, only synthetic and plastic waste materials are presented in this review paper and will be discussed in the next sections.

3.1 Synthetic fibers

Synthetic means man-made or artificial, so man-made fibers or artificial fibers are generally named synthetic fibers. These fibers are usually made from petrochemicals, and other specific types are made from natural materials such as cellulose. Thus, the mechanical characteristics of synthetic fibers mainly depend on the properties of the materials made from them. Moreover, the methods of fiber production also affect the properties of those fibers [1, 3, 11]. Synthetic fibers are made for many purposes in civil engineering constructions and can often be produced cheaply and in large quantities as compared to natural fibers [39]. Different types of synthetic fibers are used in construction applications, these types are polymeric, glass, steel, plastic, basalt and carbon fibers [40-42]. Table (1) illustrates some of the papers conducted on synthetics fiber-reinforced soils.

[43] evaluated the polypropylene and nylon fibers with class F fly ash as potential stabilizers in improving volume change characteristics of sulfate rich expansive soils. The test results illustrated enhancing in decreasing shrinkage, swelling and plasticity properties of soils and the most effective treatment was noticed with nylon fibers. The maximum enhancements of fiber treated soils were noted with 0.2% fibers and as fiber percent increase these enhancements were decreased. This behavior was due to poor compaction at higher percentages of fiber and the formation of large voids among fibers and soil grains.[44] reported that, the use of polypropylene fibers in the reinforcing sandy soil improved the strength properties and transformed the behavior of cemented reinforced samples from brittle behavior to ductile ones.

In another study carried out by [45] The unconfined compressive strength and California bearing ratio increased with polypropylene fibers addition. Moreover, the direct shear strength of reinforced soil samples increased with the presence of fibers due to increasing the cohesion value. While the angle of internal friction did not change significantly with fiber addition as reported by the authors.[13] examined the mechanical interaction behavior between soil grains and polypropylene fibers as illustrated in Fig.4. They observed that the interfacial shear resistance among fiber and soil grains is mainly related to the fiber surface roughness, re-arrangement resistance of soil grains, the effective contact area between fiber/soil, and soil components.[18] concluded that the addition of 0.5% of polyester fibers to the clay soil leads to increasing both the CBR and indirect tensile (Brazilian) strength. This result was proofed during scanning electron microscopic test which illustrated that the reinforced soil samples were a dense matrix than unreinforced one. For steel fibers, many kinds of research have illustrated that when steel fibers are present in concrete structures, there are many enhancements in the overall strength properties. These fibers enhance the concrete behaviour in terms of resistance to fatigue, ductility, cracking, shrinkage and toughness. Moreover, strength properties, like compressive, flexural and tensile strengths are increased with steel fibers additions]49,50[.

The increasing in strength is attributed to that, steel fibers absorbed the applied energy and control the cracks propagation. Finally, the only disadvantage of steel fibers (compared with to steel reinforcement) is it vulnerable to corrosion which resulting to deterioration of the concrete materials.

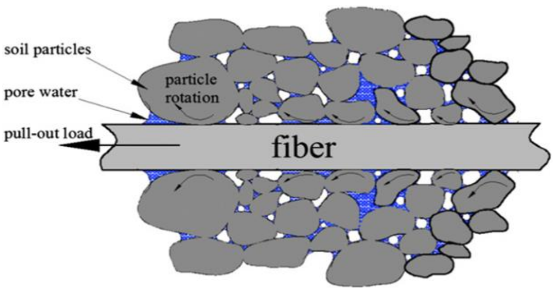

Fig.4 Sketch drawing of interfacial mechanical interactions between soil particles and fiber [45]

3.2 Plastic waste materials as fibers

Plastic means a material that is used to define extensive kinds of synthetic or semi-synthetic materials. These materials are used in a wide range of applications and huge quantities. Plastic materials can separate according to the chemical structure of the monomers that their polymer is made from. Plastic waste materials cannot be easily recycled due to their difficult chemical composition. Plastic materials are also not biodegradable materials means that they cannot crumble into smaller molecules under environmental conditions rather they can survive for a long time [55].

In many parts of the world, plastic waste materials have been producing environmental and disposal problems. Using these materials in construction can solve disposal problems in an environmentally friendly and cost-effective manner. Plastic waste materials can be used as fibers and fall into two categories: (1) short fibers (i.e., discontinuous fibers) with aspect ratios ranging from 20 to 60, and (2) long fibers (i.e. continuous fibers) having aspect ratio ranged between 200 to 500. The applications of plastic waste materials in different civil constructions are still overgrowing related to their low cost and ease of production.

Table (2) illustrates some of the papers conducted on plastic waste materials reinforced soils.[56] carried out an experimental study to examine the impact of randomly distributed fiber on the engineering characteristics of two different types of fly ash. Two different types of polyester fiber as recycled plastic waste were used. The test results illustrated that fiber addition had a significant influence on the behavior of the reinforced samples. The reinforced samples reached peak axial stresses at higher strain values than unreinforced ones, then the deformation continued under reducing axial stress. Also, these reinforced samples showed a largely ductile behavior as compared with unreinforced ones. The unconfined compressive and shear strength values increased with fiber additions.[57] performed laboratory tests to evaluate the properties of sandy silt soil reinforced with nylon carpet waste fibers. They observed that the triaxial strength increased by 204% with 3% carpet fibers addition, also the elasticity of soil samples increased. Furthermore, in situ trials have shown that fibers of 70 mm in length can be mixed with the soil with traditional equipment. The availability of such cheap fibers could lead to broader use of reinforced soil and more cost-effective construction. But this enhancement is not examined when using other types of fibers.[58] evaluated the effect of waste plastic bottle fibers on consolidation properties of reinforced sandy-silt soil with clay. Three different aspect ratios of bottle fibers (2, 4 and 8) have been used in the experimental program. The test results illustrated that the compression and volume compressibility indices decrease with fiber addition up to a certain limit and then increased with further addition of fiber.[63]

Table 1. Some of research papers conducted on synthetics fiber-reinforced soils

Authors Names	Locations	Soil Type	Fiber Type	Length (mm)	Fiber Percent (%)	Types of Tests	Conclusions
Yetimoglu & Salbas,2003[46]	Turkey	Sand	Polypropylene Fiber	20	0.0-1.0	Direct Shear Test	Fiber addition could offer a lesser loss of strength and alteration behavior of sandy soil from brittle to more ductile one. The friction angle of this soil type tends tobe increased by including the Fibers.
Khattak & Alrashidi,2006 [47]	Mississippi river	Different Types of Soil (CL-ML, CL, CH)	Polypropylene Fiber	12	0.0-0.5	Unconfined Compression and Indirect Tensile Tests	The horizontal deformation rate was considerably lesser for fibrous cemented soil mixtures. Also, there are significant increases in the tensile strength of soil samples. The soil samples reinforced with optimum fiber percentage could resist the tensile stresses in the soil–cement mixtures which may be used for road bases.
Tang et al.,2007 [48]	China	clay	Polypropylene Fiber	12	0.0-0.5	Unconfined Compression and Triaxial Tests	The addition of fibers within natural and cement-treated soil samples leads to an increase in the unconfined strength, shear strength and strain at failure. The increasing fiber content in the soil mixture could increase the axial stress and reduces the stiffness and the loss of peak strength.
Park,2009[49]	Korea	Sand	polyvinyl alcohol Fiber	12	0.0-1.0	Unconfined Compression Test	The strength of fibrous cemented-soil increases as the number of fiber inclusion layers increases.When the soil was reinforced throughout five layers of fibers, the strength was twice as strong as natural soil samples and was 1.5times greater than samples with one fiber layer.
Lovisa et al.,2010 [50]	Australia	Sand	Glass Fiber	10 and 15	0.25	Direct Shear Test	Both reinforced and unreinforced dry dense sand have higher peak angles of friction than wet sands. Similar behavior was noticed for dry and wet loose sands.

Table1. Continued

Authors Names	Locations	Soil Type	Fiber Type	Length (mm)	Fiber Percent (%)	Types of Tests	Conclusions
Estabragh et al.,2011[51]	Iran	Clay	Nylon fibers	4	1.0-3.0	One Dimensio-naConsolida-tion and Consolidated Undrained	Pre-consolidation pressure reduces, while the coefficients of swelling and compression increase with fiber addition. Fiber inclusion causes a significant increase in shear strength parameters and the stiffness of reinforced soil samples.
Hamidi & Hooresfand, 2013 [52]	Iran	Sand	Polypropylene Fiber	12	0.0-1.0	Triaxial Compression Test	The presence of fiber within cemented soil samples increases Shear strength parameters, peak, and residual shear strengths. While the initial stiffness and brittleness, index reduce with fiber addition.
Li et al.,2014[53]	East china	Clay	Polypropylene Fiber	12	0.0-2.0	Direct Tensile Test	The direct tensile strength increases with increasing fiber percent and the increasing percent was 65.7% when fiber increased from 0 to 0.2%. The tensile strength of reinforced samples was affected by dry density and water content values, as dry density increased the direct tensile strength increased. Decreasing water content causes a reduction in tensile strength values.
Patel & Singh,2019[54]	India	Clay	Glass Fiber	20	0.0-1.0	California Bearing Ratio (CBR)	For any percent of fiber, the penetrationresistance of soil samples increases even for 1.0 mm penetration. The CBR value increases with fiber addition up to a certain limit (i.e., 0.75%) and this value was 2.48 times unreinforced soil samples.
Nezhad et al.,2021[18]	Iran	Silty Clay	Synthetic Polyester Fiber	2.5-7.5	0.0-2.0	Indirect Tensile strength, CBR, Triaxial Compression Tests	Increasing fiber percent had a considerableeffect on shear parameters, indirect tensile strength and CBR. With fiber addition, the cohesion and friction angle increased by (70 and 100%), respectively. The increase in fiber length enhanced the aforementioned strength values.

examined the influence of plastic waste fibers from water bottles as reinforcing elements mixed with soil. Different triaxial compression and consolidation tests have been conducted with various percentages of plastic waste. The findings are illustrated in the form of stress-strain response and compression paths. It is observed that the strength of the soil improved with the addition of plastic waste and a significant reduction in compression parameters.[64] performed an experimental study to examine the California bearing ratio (CBR) behavior of red mud reinforced with different waste plastic water bottle fibers percent. The results showed that the soaked and unsoaked CBR values increased with the plastic percent and were found to be optimum at 2% waste plastic fibers percent.[65] examined the engineering behavior of highly plastic silty soil treated with rice husk ash blended with lime, and reinforced with plastic waste fibers. Various CBR, triaxial compression, unconfined compression and indirect tensile tests were conducted on the reinforced treated soil samples. The findings illustrated that the strength properties, durability and stability of reinforced treated soil samples are enhanced with both chemical agents and reinforced materials. Furthermore, the optimum fiber percent was vary depending on strength properties. [66] performed a comprehensive study on the use of carpet waste fibers with clay soils. Two types of carpet waste fibers with various adding percents were examined and evaluated. The study has shown that the incorporation of these fibers into soil samples can increase the UCS and change the failure behavior from brittle to ductile. The increase in the UCS is mainly related to the both initial water content and dry density of the soil samples.

4. ADVANTAGES AND DISADVANTAGES OF SYNTHETICS AND WASTE MATERIALS FIBERS

Synthetics and waste materials fibers exhibit many advantages when used in geotechnical engineering applications. Mainly, adding fiber with soil is simply and easy, especially when using a randomly distributed method. In this method, discrete fibers are added to the soil, like chemical additives (i.e. cement, lime, etc.) [65] . Further, this method shows strength isotropy and reduces the weakness planes that can present in soil-fiber mixtures. [66] Another benefit of fiber reinforcement is the restraint of crack propagation in soil samples after initial formation. [67] suggested that before cracking, the fibers seemed to have no obvious influence on the soil behavior. Since the presence of fibers alters the mechanism of failure by preventing the crack propagation [44] [68] [69][70].

Synthetic fibers have good properties and represent one of the most commonly used fibers. They are noncorrosive materials and have excellent resistance to alkalis and chlorides. Therefore, these fibers represent suitable materials for a varied range of applications [3]. Also, some types of synthetic fibers like Polyethylene terephthalate have the highest value of density and best mechanical properties [39]. Most synthetic fibers have good elasticity and acceptable durability. also, they are less expensive and are more readily available. Further, most synthetic fibers can resist the highest loads as compared with natural fibers. [71] [72] showed that, a significant enhancement in shear strength parameters of glass fiber reinforced-soil happened. Also, they point out that, the availability and non-biodegradable properties of glass fiber is advantage and proof that this type of fiber can be used for long-term soil enhancement.

Plastic waste materials as fibers could be utilized in geotechnical applications as a cost-effective, sustainable choice, and environmentally friendly [73]. The main benefit of using plastic waste materials in construction is that the energy and the resources of natural materials can be preserved. Further, the energy used for the burning of landfill materials can be reduced. [74] suggested that, the plastic waste materials should be recycled to reduce their negative environmental effects. The advantages of recycling these materials are reusing them and the decrease of using natural materials like soil in geotechnical applications. The production of industrial waste has increased in recent years due to the presence of industrial factories that produce large quantities of lime and fly ash [75], using one of these compounds along with fibers and soil can improve the soil's durability properties during repeated drying and wetting cycles. [76] mentioned that plastic waste fibers have two advantages in geotechnical engineering. Firstly, improving the engineering characteristics of soils and secondly, the use of these non-degradable waste materials in soil reinforcement also decreases environmental damage.

Mechanical compaction in the field increases the unit weight of soil by (14-32) %, However, the presence of fibers in the soil is not affected by the type of compaction [77], as the unit weight of the soil decreases in the presence of fibers.

A disadvantage of synthetic fibers is that their low-density value causes floating problems in some soil-fibers mixtures. Further, synthetic fibers have small hydrophilic properties as they are hydrophobic. This behavior affects their bonding characteristics with certain mixtures [39].

Table 2. Some of research papers conducted on plastic waste fiber-reinforced soils

Authors Names	Locatio ns	Soil Type	Fiber Type	Length (mm)	Fiber Percent (%)	Types of Tests	Conclusions
Consoli et al.,2002[30]	Brazil	Fine Sand	Plastic Waste (Polyethy lene terephthal ate)	12-36	0.0-0.78	Unconfined Compression, Splitting Tensile and Triaxial Compression Tests	The compressive and tensile strengths of the cemented soil samples were improved by fiber addition by 40% and 78%mrespectively. In triaxial test, the peak strength, post-peak behavior, shear strength parameters, energy absorption capacity and ductility enhanced with fiber addition. More enhancement values were observed for soil samples reinforced with the longer fiber.
Ghiassian et al.,2004[57]	Iran	Silty Sand	Carpet Waste	5-45	0.0-1.0	Consolidated Drained Triaxial Test	Fiber inclusion improved the peak and residual strength, modulus of elasticity and ductility of soil samples. At any fiber percent, the influence of reinforcement on the strength and volume change of soil samples is more pronounced at a larger aspect ratio of fibers.
Miraftab& Lickfold,2008[59]	United Kingdo m	Sandy Clay	Carpet Waste	0.2-14	0.0-10.0	Triaxial Compression Test	The findings recommend that the addition of as much as 10% carpet fibers can be tolerated and would increase cohesion, shear strength as the load-bearing capacity of this type of soil.
Choudharyet al.,2010[60]	India	Sandy	Plastic Waste (Polyethy lene terephthal ate)	12	0.0-4.0	CBR Test	The inclusion of fibers enhanced the CBR value and the CBR of the reinforced samples increased three times that of the unreinforced one. The maximum CBR and modulus of elasticity values are achieved at the higher fiber content.

Table2.Continued

Authors Names	Locations	Soil Type	Fiber Type	Length (mm)	Fiber Percent (%)	Types of Tests	Conclusions
Changizi & Haddad,2015 [61]	Iran	Clay	recycled polyester fiber	20	0.0-5.0	Unconfined Compression and Direct Shear Tests	Recycled polyester fiber with Nano-silica increased the unconfined compressive and direct shear strength values. The addition of Nano-silica causes a reduction in the strain at failure, while the recycled polyester fiber increases this value. Finally, recycled polyester fiber has a positive effect on soil behaviors.
Jigheh, 2016 [62]	Turkey	Clay	Plastic Waste of Water Bottles	8	More than 1.0	Triaxial Compression Test	The presence of plastic waste fibers increased the shear strength of soil and the strength value increased by 11% when reinforced with more than 1.0% fiber content .
Yadav& Tiwari, 2017 [63]	India	Clay	Waste Rubber Fibers	15	0.0-10.0	Unconfined Compression and Splitting Tensile Tests	The addition of rubber fibers up to 2.5% improved the unconfined compressive and split tensile strength values of the natural soil samples.
Peddaiah et al.,2018 [64]	India	Fine Grained Soil	Plastic Waste of Water Bottles	15-35	0.0-0.7	Direct Shear and CBR Tests	There is an important increment in shear strength parameters and CBR value of fiber-reinforced soil samples. The quantum of enhancement in the soil strengths is governed by plastic waste percent and the dimension of this waste.

Moreover, some types of synthetic fibers (like PET fibers) take large energy to produce due to the manufacturing method, therefore the cost of this type of fibers could be more costly. There are some limitations of synthetic fibers (especially polymeric fibers) including their recycling and reusing. If the previous history of these fibers is unknown and they are collected from an uncontrolled environment, the risks happen. This resulting unstable and inconsistent characteristic of these fibers [78]. The disadvantages of using plastic waste fibers in geotechnical applications be governed by what application they are being used for. Also, the cost of recycling and reusing these materials could often be greater than the cost of raw materials, which bounds their efficiency for use [74]. Another thing, there are still no scientific standard specifications for using plastic waste materials in soil reinforcement applications, mainly for field applications.

5. APPLICATION

The applications of synthetic and plastic waste materials fibers are still increasing rapidly due to their low cost and ease of production. A wide-ranging of literature review demonstrates that using synthetic and plastic waste materials fibers in geotechnical applications is feasible in different fields. These fields include concrete works, road construction, bearing soil layers for foundations, retaining walls and railway embankments. The following paragraphs present some applications of synthetic and plastic waste materials fibers in geotechnical engineering.

[14] observed that, the adding of plastic waste fibers as aggregate in concrete (up to a certain level) can enhance the abrasion resistance of concrete. This property is important in many practical applications such as hydraulic structures and concrete pavement blocks. [79] found that, the plastic waste fibers can be used to replace a part of the aggregates in concrete, resulting in reducing the total unit weight of the concrete. This type of mixture (i.e., non-bearing lightweight concrete) is suitable for some applications such as concrete panels used in facades. [80] concluded that the sand fiber-reinforced soils were viable alternative materials in road construction for low traffic or temporary roads. From full-scale field tests, found that the presence of synthetic fibers in road [81] layers can improve pavement resistance to rutting, unlike to unreinforced soil pavement when constructed on a weak subgrade. [82] reported that the fiber-reinforced cemented sand increases the bearing capacity of spread footings and can be used in field applications. [83] illustrated that the use of synthetic fibers reinforced sand behind retaining walls enhances the stability of the wall and reduces the lateral earth pressure values. They also documented that these effects are more significant when short fibers are used together with a geo-grid. [20] mentioned that the soil reinforcement can be used as reinforced soil retaining wall, which is an alternative to a conventional concrete retaining wall. In such structures, the reinforcement acts as a tensile element shared to the soil by friction and interlocking, resulting to enhances the stability of the soil mass. By analyzing their finding result. Another study by [84] presented that the enhancement of the local soil by the inclusion of randomly distributed fibers could be used for shallow footings, especially when deep footings represent unsuited solutions due to their higher costs. Finally, throughout numerous types of research, it has been highlighted that the fiber content used to reinforce soil is very significant. In general, not always higher fiber content is better for soil reinforcement. Sometimes the mechanical properties of soils improved with fibers addition up to a certain limit, then decrease. Thus, it is important to determine the optimal fiber content when used to reinforce soils. Moreover, the physical properties of fibers (i.e., length, shape, etc.) also affect the efficiency of fiber-reinforced soil.

6. CONCLUSION

From this review paper the following conclusions could be drawn:

- The hand-mixing method of randomly distributed fibers allows fibers to combine with the soil mass in proper form.
- The easy way of recycling plastic waste materials as reinforcement fibers meet a great interest in geotechnical engineering applications.
- The low-cost, availability, ease of work and possibility of use in all-weather circumstances are the overall advantages of synthetic and plastic waste fibers composite soils.
- Chemical treatment (using cement, lime, fly ash, etc.) can also be used to enhance the mechanical properties of fiber-reinforced soils, resulting in the development high performing matrices.
- The degree of adhesion, bonding and interaction between soil and fiber are very important factors that affect the engineering behavior of the soil-fiber mixtures.
- The practical benefits of soil reinforcement consist of increasing soil strength, reducing tensile cracks and decreasing soil brittleness.

A successful application might help to decrease the quantity of plastic waste materials disposed of in landfills. Also, this application contributes to sustainable development by giving low-cost materials to geotechnical engineering applications.

7. RECOMMENDATIONS

From the authors' point of view, the research papers on the use of synthetic and plastic waste fibers with cohesive soils have been limited. Thus, further studies need to evaluate the mechanisms of load transformation on the interfaces between clays and fibers. In field applications, much attention is necessary to achieve a reasonably uniform distribution of the fibers within the soil mass. Scale properties affect the behavior of fiber-reinforced soils (like stress-strain behavior). Thus, additional large-scale tests are recommended so that fiber-reinforced soil behavior will be well understood. Lastly, the long-term durability of fiber-reinforced soils and the long-term behavior of plastic waste fibers are recommended. Declaration of interes the authors declare that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

Author Contributions
Farah Z. MISHAAL: Investigation, Methodology, Writing- original draft preparation. Abdulrahman Aldaood: Writing- Reviewing and Editing.

List of symbols

CBR	California bearing ratio
UCS	Unconfined compressive strength
Mr	Resilient modulus
PET	Polyethylene terephthalate
CL	Low plasticity clay
ML	Low plasticity silt
CH	High plasticity clay

REFERENCES

[1] A. Siddika, M. A. Al Mamun, R. Alyousef, and Y. M. Amran, "Strengthening of reinforced concrete beams by using fiber-reinforced polymer composites: A review," Journal of Building Engineering, vol. 25, p. 100798, 2019.

[2] A. Laborel-Préneron, J.-E. Aubert, C. Magniont, C. Tribout, and A. Bertron, "Plant aggregates and fibers in earth construction materials: A review," Construction and building materials, vol. 111, pp. 719-734, 2016.

[3] S. M. Hejazi, M. Sheikhzadeh, S. M. Abtahi, and A. Zadhoush, "A simple review of soil reinforcement by using natural and synthetic fibers," Construction and building materials, vol. 30, pp. 100-116, 2012.

[4] S. Bordoloi, S. Sekharan, and A. Garg, "A review of physio-biochemical properties of natural fibers and their application in soil reinforcement," Advances in Civil Engineering Materials, vol. 6, no. 1, pp. 323-359, 2017.

[5] A. Mittal and S. Shukla, "Effect of Random Inclusion of Kenaf Fibres on Strength Behaviour of Poor Subgrade Soils," Jordan Journal of Civil Engineering, vol. 14, no. 1, 2020.

[6] A. Taiyab, N. N. Islam, and M. Rahman, "Desiccation characteristics and direct tension attributes of thin clayey soil containing discrete natural fibers," Soils and Rocks, vol. 45, 2022.

[7] I. Benessalah, A. Arab, P. Villard, M. Sadek, and A. Kadri, "Laboratory study on shear strength behaviour of reinforced sandy soil: effect of glass-fibre content and other parameters," Arabian Journal for Science and Engineering, vol. 41, pp. 1343-1353, 2016.

[8] F. Ahmad, F. Bateni, and M. Azmi, "Performance evaluation of silty sand reinforced with fibres," Geotextiles and geomembranes, vol. 28, no. 1, pp. 93-99, 2010.

[9] S.-S. Park, "Unconfined compressive strength and ductility of fiber-reinforced cemented sand," Construction and building materials, vol. 25, no. 2, pp. 1134-1138, 2011.

[10] I. M Al-Kiki, A. H Al-Zubaydi, and M. A Al-Atalla, "Compressive and tensile strength of fibrous clayey soil stabilized with lime," Al-Rafidain Engineering Journal (AREJ), vol. 20, no. 2, pp. 66-77, 2012.

[11] S. K. Shukla, Fundamentals of fibre-reinforced soil engineering. Springer, 2017.

[12] A. Aldaood, M. Bouasker, and M. Al-Mukhtar, "Mechanical behavior of gypseous soil treated with lime," Geotechnical and Geological Engineering, vol. 39, pp. 719-733, 2021.

[13] C.-S. Tang, B. Shi, and L.-Z. Zhao, "Interfacial shear strength of fiber reinforced soil," Geotextiles and Geomembranes, vol. 28, no. 1, pp. 54-62, 2010.

[14] N. Saikia and J. De Brito, "Use of plastic waste as aggregate in cement mortar and concrete preparation: A review," Construction and Building Materials, vol. 34, pp. 385-401, 2012.

[15] S. Dixit, "Effect of waste plastic on the strength characteristics of the subgrade for the flexible pavement," GRD Journal-Global Research and Development Journal for Engineering, vol. 2, no. 11, 2017.

[16] A. K. Jassim, "Recycling of polyethylene waste to produce plastic cement," Procedia manufacturing, vol. 8, pp. 635-642, 2017.

[17] Ö. L. Ertuğrul and F. İnal, "Assessment of the artificial fiber contribution on the shear

strength parameters of soils," Advanced Engineering Days (AED), vol. 1, pp. 114-117, 2021.
[18] M. G. Nezhad, A. Tabarsa, and N. Latifi, "Effect of natural and synthetic fibers reinforcement on California bearing ratio and tensile strength of clay," Journal of Rock Mechanics and Geotechnical Engineering, vol. 13, no. 3, pp. 626-642, 2021.
[19] K. W. A. A.-K. Khalid, W. Abd Al-Kaream, M. Y. Fattah, and M. K. H. M. K. Hameedi, "Compressibility and strength development of soft soil by polypropylene fiber," Geomate Journal, vol. 22, no. 93, pp. 91-97, 2022.
[20] S. Shukla, N. Sivakugan, and B. Das, "Fundamental concepts of soil reinforcement—an overview," International Journal of Geotechnical Engineering, vol. 3, no. 3, pp. 329-342, 2009.
[21] A. Aldaood, A. Khalil, M. Bouasker, and M. AL-Mukhtar, "Experimental study on the mechanical behavior of cemented soil reinforced with straw fiber," Geotechnical and Geological Engineering, vol. 39, pp. 2985-3001, 2021.
[22] I. M. Alkiki, M. D. Abdulnafaa, and A. Aldaood, "Geotechnical and other characteristics of cement-treated low plasticity clay," Soils and Rocks, vol. 44, 2021.
[23] A. Mohajerani et al., "Amazing types, properties, and applications of fibres in construction materials," Materials, vol. 12, no. 16, p. 2513, 2019.
[24] T. Hou, J. Liu, Y. Luo, and Y. Cui, "Triaxial compression test on consolidated undrained shear strength characteristics of fiber reinforced soil," Soils and Rocks, vol. 43, no. 1, pp. 43-55, 2020.
[25] S. A. Khattab, I. M. Al-Kiki, and A. H. Al-Zubaydi, "Effect of Fibers on Some Engineering Properties of Cement and Lime Stabilized Soils," Engineering and Technology Journal, vol. 29, no. 5, pp. 886-905, 2011.
[26] F. Chebet and D. Kalumba, "Laboratory investigation on re-using polyethylene (plastic) bag waste material for soil reinforcement in geotechnical engineering," Civil Engineering and Urban Planning: An International Journal (CiVEJ), vol. 1, no. 1, pp. 67-82, 2014.
[27] A. Aldaood, A. Khalil, and I. Alkiki, "Impact of randomly distributed hay fibers on engineering properties of clay soil," Jordan Journal of Civil Engineering, vol. 14, no. 3, 2020.
[28] S. P. K. Kodicherla, J. Muktinuthalapati, and N. Revanna, "Effect of Randomly Distributed Fibre Reinforcements on Engineering Properties of Beach Sand," Jordan Journal of Civil Engineering, vol. 12, no. 1, 2018.
[29] M. Mistry, T. Shukla, P. Venkateswalu, S. Shukla, C. Solanki, and S. K. Shukla, "A new mixing technique for randomly distributed fibre-reinforced expansive soil," in Environmental Geotechnology: Proceedings of EGRWSE 2018, 2019: Springer, pp. 161-171.
[30] N. C. Consoli, J. P. Montardo, P. D. M. Prietto, and G. S. Pasa, "Engineering behavior of a sand reinforced with plastic waste," Journal of geotechnical and geoenvironmental engineering, vol. 128, no. 6, pp. 462-472, 2002.
[31] P. K. Pradhan, R. K. Kar, and A. Naik, "Effect of random inclusion of polypropylene fibers on strength characteristics of cohesive soil," Geotechnical and Geological Engineering, vol. 30, pp. 15-25, 2012.
[32] S. Krishna Rao and A. M. Nasr, "Laboratory study on the relative performance of silty-sand soils reinforced with linen fiber," Geotechnical and Geological Engineering, vol. 30, pp. 63-74, 2012.
[33] H. Sarbaz, H. Ghiassian, and A. A. Heshmati, "CBR strength of reinforced soil with natural fibres and considering environmental conditions," International Journal of Pavement Engineering, vol. 15, no. 7, pp. 577-583, 2014.
[34] S. AbdulRahman, M. Fattah, and E. Ihsan, "Influence of plastic fiber on the geotechnical properties of gypseous soil," International Journal of Engineering, vol. 34, no. 2, pp. 367-374, 2021.
[35] B. J. Nareeman and M. Y. Fattah, "Effect of Soil Reinforcement on Shear Strength and Settlement of Cohesive Frictional Soil," GEOMATE Journal, vol. 3, no. 5, pp. 308-313, 2012.
[36] P. Saha, S. Chowdhury, D. Roy, B. Adhikari, J. K. Kim, and S. Thomas, "A brief review on the chemical modifications of lignocellulosic fibers for durable engineering composites," Polymer Bulletin, vol. 73, pp. 587-620, 2016.
[37] A. E. M. K. Mohamed, "Improvement of swelling clay properties using hay fibers," Construction and Building Materials, vol. 38, pp. 242-247, 2013.
[38] M. Bouasker, N. Belayachi, D. Hoxha, and M. Al-Mukhtar, "Physical characterization of natural straw fibers as aggregates for construction materials applications," Materials, vol. 7, no. 4, pp. 3034-3048, 2014.
[39] L. Menezes, D. Sousa, S. Fucale, and S. Ferreira, "Analysis of the physical-mechanical behavior of clayey sand soil improved with coir fiber," Soils and Rocks, vol. 42, no. 1, pp. 31-42, 2019.
[40] S. Yin, R. Tuladhar, F. Shi, M. Combe, T. Collister, and N. Sivakugan, "Use of macro plastic fibres in concrete: A review," Construction and Building Materials, vol. 93, pp. 180-188, 2015.
[41] J. R. Roesler, S. A. Altoubat, D. A. Lange, K.-A. Rieder, and G. R. Ulreich, "Effect of synthetic fibers on structural behavior of concrete slabs-on-ground," ACI materials journal, vol. 103, no. 1, p. 3, 2006.
[42] M. Malekzadeh and H. Bilsel, "Hydro-mechanical behavior of polypropylene fiber

reinforced expansive soils," KSCE Journal of Civil Engineering, vol. 18, pp. 2028-2033, 2014.

[43] H. Jamshaid and R. Mishra, "A green material from rock: basalt fiber–a review," The Journal of The Textile Institute, vol. 107, no. 7, pp. 923-937, 2016.

[44] K. Punthutaecha, A. J. Puppala, S. K. Vanapalli, and H. Inyang, "Volume change behaviors of expansive soils stabilized with recycled ashes and fibers," Journal of materials in Civil Engineering, vol. 18, no. 2, pp. 295-306, 2006.

[45] N. C. Consoli, M. A. Vendruscolo, A. Fonini, and F. Dalla Rosa, "Fiber reinforcement effects on sand considering a wide cementation range," Geotextiles and Geomembranes, vol. 27, no. 3, pp. 196-203, 2009.

[46] A. S. Zaimoglu and T. Yetimoglu, "Strength behavior of fine grained soil reinforced with randomly distributed polypropylene fibers," Geotechnical and Geological Engineering, vol. 30, pp. 197-203, 2012.

[47] T. Yetimoglu and O. Salbas, "A study on shear strength of sands reinforced with randomly distributed discrete fibers," Geotextiles and geomembranes, vol. 21, no. 2, pp. 103-110, 2003.

[48] M. J. Khattak and M. Alrashidi, "Durability and mechanistic characteristics of fiber reinforced soil–cement mixtures," The International Journal of Pavement Engineering, vol. 7, no. 1, pp. 53-62, 2006.

[49] C. Tang, B. Shi, W. Gao, F. Chen, and Y. Cai, "Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil," Geotextiles and Geomembranes, vol. 25, no. 3, pp. 194-202, 2007.

[50] S.-S. Park, "Effect of fiber reinforcement and distribution on unconfined compressive strength of fiber-reinforced cemented sand," Geotextiles and Geomembranes, vol. 27, no. 2, pp. 162-166, 2009.

[51] J. Lovisa, S. Shukla, and N. Sivakugan, "Shear strength of randomly distributed moist fibre-reinforced sand," Geosynthetics International, vol. 17, no. 2, pp. 100-106, 2010.

[52] A. Estabragh, A. Bordbar, and A. Javadi, "Mechanical behavior of a clay soil reinforced with nylon fibers," Geotechnical and Geological Engineering, vol. 29, pp. 899-908, 2011.

[53] A. Hamidi and M. Hooresfand, "Effect of fiber reinforcement on triaxial shear behavior of cement treated sand," Geotextiles and Geomembranes, vol. 36, pp. 1-9, 2013.

[54] J. Li, C. Tang, D. Wang, X. Pei, and B. Shi, "Effect of discrete fibre reinforcement on soil tensile strength," Journal of Rock Mechanics and Geotechnical Engineering, vol. 6, no. 2, pp. 133-137, 2014.

[55] S. K. Patel and B. Singh, "Investigation of glass fiber reinforcement effect on the CBR strength of cohesive soil," in Ground Improvement Techniques and Geosynthetics: IGC 2016 Volume 2, 2019: Springer, pp. 67-75.

[56] S. Mali, S. Kadam, S. Mane, K. Panchal, S. Kale, and Y. Navkar, "Soil stabilization by using plastic waste," Int. Res. J. Eng. Technol. (IRJET), vol. 6, pp. 4056-4060, 2019.

[57] S. R. Kaniraj and V. Gayathri, "Geotechnical behavior of fly ash mixed with randomly oriented fiber inclusions," Geotextiles and Geomembranes, vol. 21, no. 3, pp. 123-149, 2003.

[58] H. Ghiassian, G. Poorebrahim, and D. H. Gray, "Soil reinforcement with recycled carpet wastes," Waste Management & Research, vol. 22, no. 2, pp. 108-114, 2004.

[59] A. Laskar and S. K. Pal, "Effects of waste plastic fibres on compaction and consolidation behavior of reinforced soil," EJGE, vol. 18, pp. 1547-1558, 2013.

[60] M. Miraftab and A. Lickfold, "Utilization of carpet waste in reinforcement of substandard soils," Journal of industrial textiles, vol. 38, no. 2, pp. 167-174, 2008.

[61] A. Choudhary, J. Jha, and K. Gill, "A study on CBR behavior of waste plastic strip reinforced soil," Emirates journal for engineering research, vol. 15, no. 1, pp. 51-57, 2010.

[62] F. Changizi and A. Haddad, "Strength properties of soft clay treated with mixture of nano-SiO2 and recycled polyester fiber," Journal of rock mechanics and Geotechnical Engineering, vol. 7, no. 4, pp. 367-378, 2015.

[63] H. Soltani-Jigheh and A. Rasulifard, "Assessing the Potential Improvement of Fine-grained Clayey Soils by Plastic Wastes," SOILS AND ROCKS, vol. 39, no. 3, pp. 333-339, 2016.

[64] J. Yadav and S. Tiwari, "Effect of waste rubber fibres on the geotechnical properties of clay stabilized with cement," Applied Clay Science, vol. 149, pp. 97-110, 2017.

[65] S. Peddaiah, A. Burman, and S. Sreedeep, "Experimental study on effect of waste plastic bottle strips in soil improvement," Geotechnical and Geological Engineering, vol. 36, pp. 2907-2920, 2018.

[66] T. Yetimoglu, M. Inanir, and O. E. Inanir, "A study on bearing capacity of randomly distributed fiber-reinforced sand fills overlying soft clay," Geotextiles and Geomembranes, vol. 23, no. 2, pp. 174-183, 2005.

[67] A. Kumar, B. S. Walia, and J. Mohan, "Compressive strength of fiber reinforced highly compressible clay," Construction and building materials, vol. 20, no. 10, pp. 1063-1068, 2006.

[68] C. E. S. Expert, "Strength and ductility of randomly distributed palm fibers reinforced silty-sand soils," American Journal of Applied Sciences, vol. 5, no. 3, pp. 209-220, 2008.

[69] N. d. S. Correia and S. A. Rocha, "Reinforcing effect of recycled polypropylene fibers on a

clayey lateritic soil in different compaction degrees," Soils and Rocks, vol. 44, 2021.
[70] A. H. Aldaood, A. A. Khalil, and I. M. Alkiki, "Soil Reinforcement Using Natural and Synthetic Fibers (A Review)," Al-Rafidain Engineering Journal (AREJ), vol. 25, no. 1, pp. 118-125, 2020.
[71] M. Y. Fattah, M. A. Yousif, and A. L. M. Rasheed, "Production of Waste Rubber-Made Geogrid Reinforcement for Strengthening Weak Soils," in Modern Applications of Geotechnical Engineering and Construction: Geotechnical Engineering and Construction, 2021: Springer, pp. 265-278.
[72] F. Ahmad, D. Mujah, H. Hazarika, and A. Safari, "Assessing the potential reuse of recycled glass fibre in problematic soil applications," Journal of Cleaner Production, vol. 35, pp. 102-107, 2012.
[73] A. H. Aldaood, I. M. Al-kiki, and M. D. Abdulnafaa, "Industrial Waste and its Impacts on the Engineering Properties of Soil: a Review," Al-Rafidain Engineering Journal (AREJ), vol. 27, no. 1, pp. 25-35, 2022.
[74] B. J. Putman and S. N. Amirkhanian, "Utilization of waste fibers in stone matrix asphalt mixtures," Resources, conservation and recycling, vol. 42, no. 3, pp. 265-274, 2004.
[75] Y. Huang, R. N. Bird, and O. Heidrich, "A review of the use of recycled solid waste materials in asphalt pavements," Resources, conservation and recycling, vol. 52, no. 1, pp. 58-73, 2007.
[76] M. Al-Obaydi, I. Al-Kiki, and A. Al-Zubaydi, "Strength and durability of gypseous soil treated with waste lime and cement," Journal Al-Rafidain Engineering, vol. 18, no. 1, pp. 28-42, 2010.
[77] I. Bozyigit, F. Bulbul, C. Alp, and S. Altun, "Effect of randomly distributed pet bottle strips on mechanical properties of cement stabilized kaolin clay," Engineering Science and Technology, an International Journal, vol. 24, no. 5, pp. 1090-1101, 2021.
[78] M. T. Al-Layla and D. Q. Nazar Al-Saffar, "Improving the engineering properties of the gypseous soil using dynamic compaction method," Al-Rafidain Engineering Journal (AREJ), vol. 22, no. 2, pp. 109-122, 2014.
[79] F. Pelisser, O. R. K. Montedo, P. J. P. Gleize, and H. R. Roman, "Mechanical properties of recycled PET fibers in concrete," Materials research, vol. 15, pp. 679-686, 2012.
[80] B. A. Manjunath, "Partial replacement of E-plastic waste as coarse-aggregate in concrete," Procedia Environmental Sciences, vol. 35, pp. 731-739, 2016.
[81] J. S. Tingle, R. L. Santoni, and S. L. Webster, "Full-scale field tests of discrete fiber-reinforced sand," Journal of transportation engineering, vol. 128, no. 1, pp. 9-16, 2002.
[82] M. S. Chauhan, S. Mittal, and B. Mohanty, "Performance evaluation of silty sand subgrade reinforced with fly ash and fibre," Geotextiles and geomembranes, vol. 26, no. 5, pp. 429-435, 2008.
[83] N. C. Consoli, M. A. Vendruscolo, and P. D. M. Prietto, "Behavior of plate load tests on soil layers improved with cement and fiber," Journal of geotechnical and geoenvironmental engineering, vol. 129, no. 1, pp. 96-101, 2003.
[84] performance of reinforced soil walls by the inclusion of short fiber," Geotextiles and geomembranes, vol. 23, no. 4, pp. 348-361, 2005.
[85] N. C. Consoli, M. A. A. Bassani, and L. Festugato, "Effect of fiber-reinforcement on the strength of cemented soils," Geotextiles and Geomembranes, vol. 28, no. 4, pp. 344-351, 2010.

تسليح التربة باستخدام الياف صناعية ومخلفات المواد البلاستيكية: بحث مقال

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الملخص

يعد مفهوم تسليح التربة من المفاهيم الأساسية في هندسة الجيوتكنيك, اذ يعد من الطرائق المهمة في تحسين الخصائص الهندسية للترب. يعتمد تسليح التربة على اضافة عناصر تسليح للتربة اذ تم استخدام انواع مختلفة من مواد التسليح ومنذ القدم. من بين مواد التسليح المختلفة: الالياف الطبيعية, الالياف الصناعية, مخلفات المواد البلاستيكية, الى اخره من المواد التي تعمل على زيادة قابلية تحمل التحمل وخاصة قابليتها ضد احمال الشد المسلطة عليها. ان اضافة الالياف الى التربة بصورة عشوائية له الاهمية الكبيرة في زيادة مقاومة الشد للتربة من خلال زيادة التداخل بين الالياف المضافة وبين جزئيات التربة من جهة وبين تقليل مستويات الضعف الناتجة عن تراكم الالياف فوق بعضها البعض من جهة اخرى. في بحث المقال هذا تم التطرق الى خصائص التربة المسلحة بالياف صناعية واخرى مسلحة بمخلفات المواد البلاستيكية. كذلك تم التعرف الى اهم مزايا ومساوى مثل هذه المواد في حالة استخدامها في التربة. تم التطرق ايضا الى التطبيقات الهندسية التي يتم فيها استخدام التربة المسلحة, واخيرا تم تقديم بعض التوصيات حول استخدام التربة المسلحة في تطبيقات هندسة الجيوتكنيك.

الكلمات الدالة :

تسليح التربة؛ الياف صناعية؛ مخلفات بلاستيكية؛ خصائص المقاومة؛ تطبيقات هندسية