Research Article

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Effect of waste materials on soil properties

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Abstract: Industrial processes are the main generator of littering agents, and the growing environmental awareness has contributed to a focus on the issue of littering. One of the biggest environmental issues in the world is how to manage this waste given the limited space available, the high cost of remediation, and the need for landfilling. However, the idea of reusing some of this waste is an alternative solution to decreasing the process of landfilling, and reducing the increase of waste. In this research, three different waste materials were used, namely plastic waste, aluminum waste, and silica sand. Each of these materials was mixed in a ratio of 1, 3, and 5%, with silty sand soil. The consistency limits of maximum dry density and the optimal ratio for the preferred materials were determined by examining and comparing cohesiveness and angle of internal friction. Research results showed that the maximum unit weight decreased after adding the waste materials: it decreased by 9.35 and 11.69% when 5% each of aluminum and plastic waste was added, respectively. At the same time, the increase in the inner angle of internal friction reached 26.41% at the highest percentage of plastic waste. The addition of 3% of silica sand gave the highest value of cohesion, and the increase reached 218.7% for soils not treated with silica. It also showed the effect of adding 1% of silica sand on the plasticity, reducing it by 72.7% from its original value.

Keywords: waste material, consistency of soil, silty sand, compaction, angle of internal friction

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1 Introduction

The aim of modification, which is one of the uses of engineering soil, whether by the chemical or mechanical method, is for the purpose of improving the soil such as the soil of sedimentary plain south of Iraq [1,2]. Furthermore, one of the aims of improvement is to improve and boost the soil's bearing capacity. On the other hand, it may help in reducing the amount of waste and its risks to the environment, in an environment-friendly and inexpensive manner, compared to the cost of materials previously used for soil stabilization. The most popular technique for stabilizing soil is to add chemicals to it. The mechanical qualities of soil have been improved by researchers using cement, lime, and other binders, but in recent years, the utilization of solid wastes including plastic, glass, metal, rubber, and fabric fibers has received attention. This was done to increase these qualities, make them easier to mix with the soil, increase the soil's shear strength due to their non-interaction and tensile strength, as well as to get rid of the waste in a helpful and healthy way because it is currently an issue for all countries. The reed fibers and industrial glass fibers were used as soil reinforcement fibers. Also fabrics, commercially available materials, were used for floor coverings. The results showed an increase in soil strength commensurate with the amount of fiber used, but this increase reached a specific value and did not exceed it [3]. The effect of adding polyethylene fibers (waste plastic bottles) was studied, randomly distributed, to fine sand, and subjected to an unconfined compression test and saturated drained tests. The results showed an increase in soil resistance by increasing the percentage of fibers [4]. A direct shear test on soil that contained plastic fibers was carried out by Naeini and Sadjadi (2008). The findings revealed an improvement in the shear coefficients (c and φ) as well as an increase in the shear strength [5]. In order to study the impact of industrial aluminum scraps on clay soil, Zuheir et al. [6] performed altered compaction and unconfined compression tests for five different additive percentages. The test findings revealed a rise in the dry density, an increase in the compression strength, and a drop in the optimal water content by increasing the proportion of aluminum added up to 10%; however, this strength reduced by raising the percentage beyond that threshold [7].

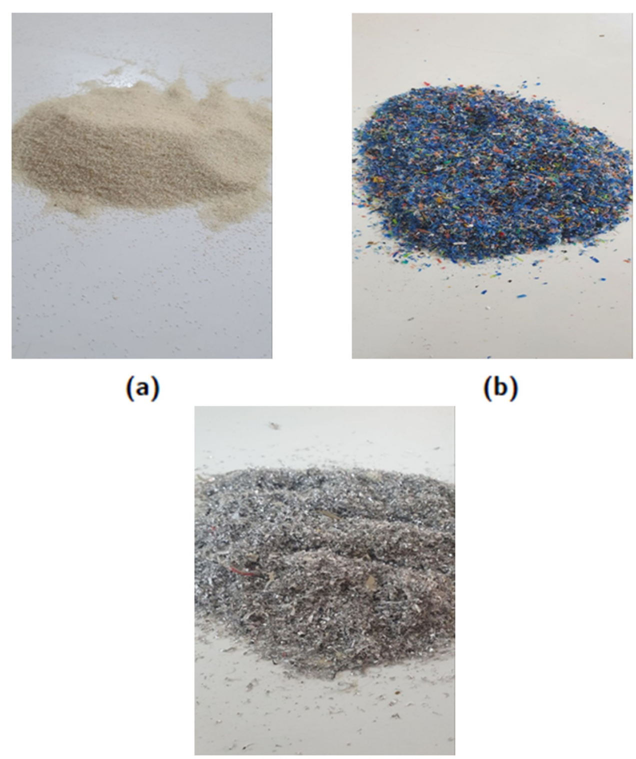
Wang et al. (2017) developed a technique to produce new, porous and permeable sandy soil from recycled glass waste and sand (glass sandy soil). The permeability of glass sandy soil was investigated using various glass waste percentages, smoothing value, and glass particle size. Research revealed that the best permeability was obtained when 20% of glass trash was recycled with sand [8]. Syed and Sudipta [9] looked into how glass powder affected cohesive soils. A significant portion of the original soil was combined with the glass powder, and the mixture was then tested for geotechnical stability. As a result of lower liquid limit (LL) and plastic limit (PL) values and higher maximum dry densities (MDDs), the plasticity index (PI) decreased. This was accomplished by raising the value of California bearing ratio and the unconfined compressive strength of the glass powder, up to 8%, while lowering the ideal moisture content. When the additive percentage was raised, though, it fell [10]. Therefore, the main objective of this study was to demonstrate the effect of adding the used waste on the properties of the soil because it is available in large quantities in the environment and is chemically inert and does not interact with the water in the soil.

2 Materials and methods

Soil: Silty sand soil from the Wasit Governorate in western Iraq was transported for use in this investigation. The physical characteristics of the soils utilized were determined through "standard tests," as indicated in Table 1. Three different forms of solid waste were used in this study. Plastic garbage was transported from Baghdad's Organization for Plastic Industries. This was divided into pieces with a thickness of 0.5 mm and a length of 1–3 mm. The substance was made of polyethylene and had a specific gravity of 0.93. Pieces of aluminum (0.3–0.6 mm in size) were collected from the waste of factories that used aluminum in the manufacture of windows, doors, and others. The soil was well dried by air, and then each of these materials was mixed in a ratio of 0, 1, 3, and 5% with the soil, and then a modified compaction test and a direct shear test were performed for the examination of the Atterberg limits. It was conducted only on the soil mixed with glass powder, due to its smoothness, because only soil that had passed through sieve no. 40 in accordance with the specifications was used for the examination. Due to the smoothness of the mixed soil – the texture check was only performed on soil passing through sieve no. 40 – the American Society for Testing and Materials' (ASTM) standards were checked for each of the additives and for each ratio with silica sand powder. This was done in accordance with the requirements of "ASTM:D 4318-00" (Figures 1 and 2).

Table 1: Physical properties of the silty sand soil

Physical properties	Index value	Standards
Specific gravity (G_s)	2.69	ASTM: D854-02
LL%	47	ASTM: D4318-00
PL%	28	ASTM: D4318-00
PI%	19	ASTM: D4318-00
Sand%	69	
Fine particles%	31	
Maximum dry unit weight (kN/m^3)	17.1	ASTM: D698
Optimum moisture content%	22.63	ASTM: D698
Soil classification (USCS)	SM	ASTM: D698ASTM: D2487-00
Angle of internal friction Φ	36.8	ASTM: D2435
Cohesion C (kPa)	11.053	ASTM: D2435



(a) (b) (c)

Figure 1: The waste materials used in the study. (a) Silica sand, (b) plastic waste, and (c) aluminum waste.

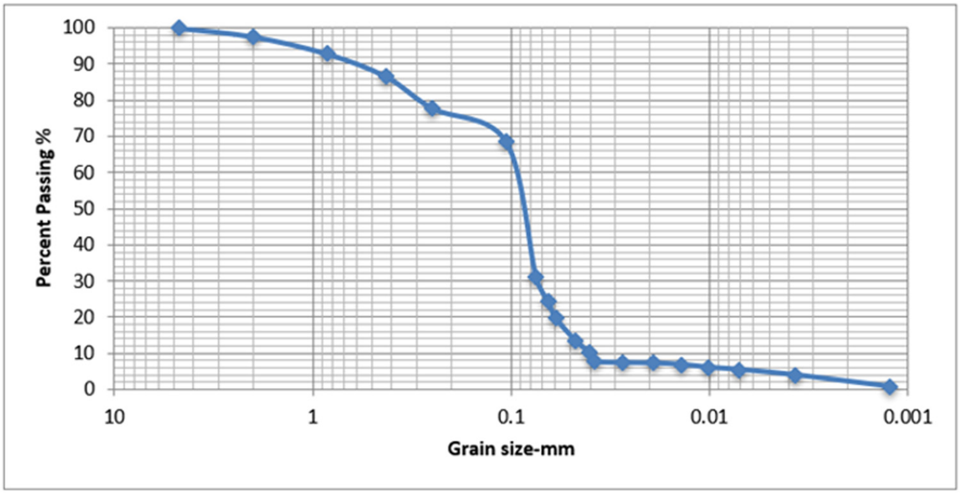


Figure 2: The grain size distribution of the soil sample.

3 Results and discussion

3.1 Compaction test

The dry soil and solid waste were combined separately for this test in conformance with ASTM D:698 in order to determine the MDD and optimal moisture content (OMC), respectively, in order to take advantage of the latter and prepare samples for "the direct shear test." However, soil samples with various water contents were prepared for Proctor Test and the size of the mold is 4 inch diameter with 3 layers and each layer was compacted 25 blows (as shown in Figure 3). The outcomes of these tests are shown in Figures 4–8.

As shown in the previous figures and Table 2, we see a drop in the dry unit weight of the soil with just a rise in waste materials. This is helpful while constructing dams, which call for using light materials. These findings concur with those made by many previous studies [11–15]. The results show that MDD was decreased 11.69 and 9.35% for each of the plastic and aluminum waste, respectively, when adding 5% for each of them, compared to that decrease that occurred when adding silica sand waste, as the percentage of reduction was (4.67, 4.03, and 1.75)% when adding silica sand by (1, 3, and 5)%, respectively. We also noticed a decrease in the optimum water content percentage only when adding 1% of the plastic waste, as it was 28.46%. Adding 1 and 5% of silica sand, it was 28.46%, whereas when adding 1 and 5% of silica sand, it was 20.46 and 12.95%, respectively. Also, adding 3% silica sand shows that the percentage of increase was not noticeable as it was

Figure 3: Proctor mold.

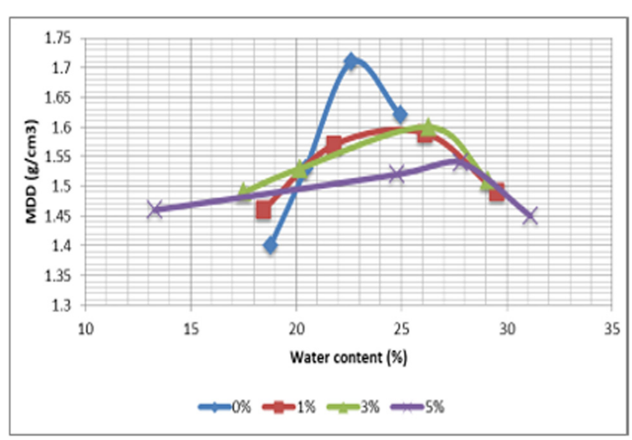


Figure 4: Compaction curves for various percentages of aluminum waste.

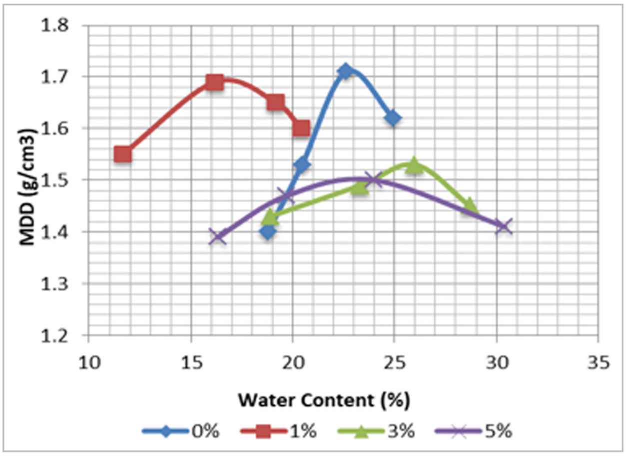


Figure 5: Compaction curves for various percentages of plastic waste.

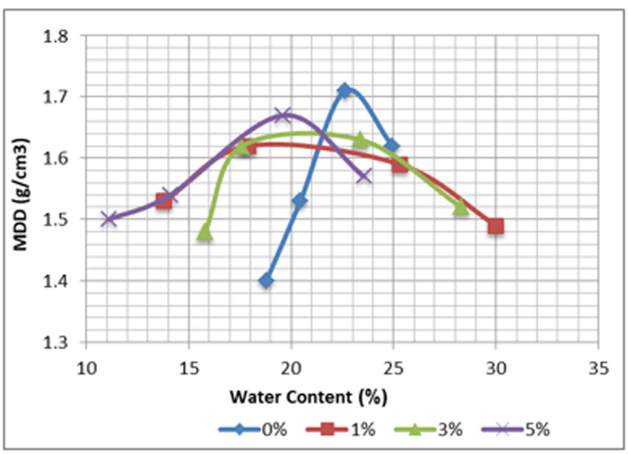


Figure 6: Compaction curves for various percentages of silica sand.

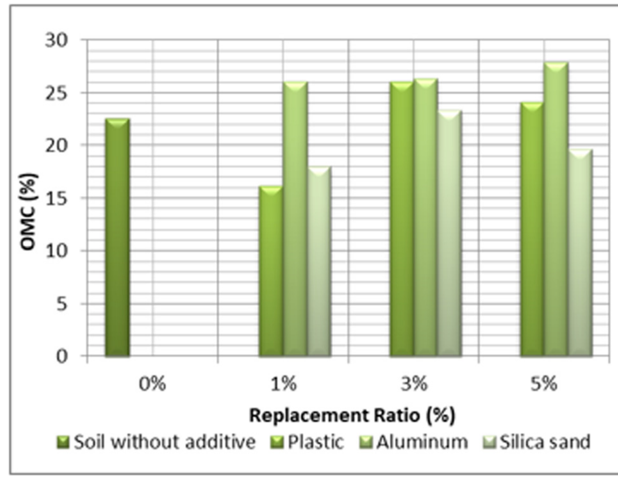


Figure 7: Variation in OMC% at various percentages of three waste materials.

3.4%. It could be the reason for the low specific gravity of plastic and aluminum waste; while silica sand has a similar composition to the original soil, there is a slight difference in value for this addition compared to the other additions. Also, we can notice a 28.45% decrease in OMC for 1% of plastic waste; at 1 and 5% of silica sand, the decrease was 20.45 and 12.94%, respectively. The optimum moisture content increases for the rest in the percentage of waste materials. This result may be that the water in the soil needs to be hydrated, which is similar to the result by Kadhim et at. [16].

3.2 Direct shear test

Direct shear test was employed on soil samples having various ratios of soild waste. As the MDD and optimum

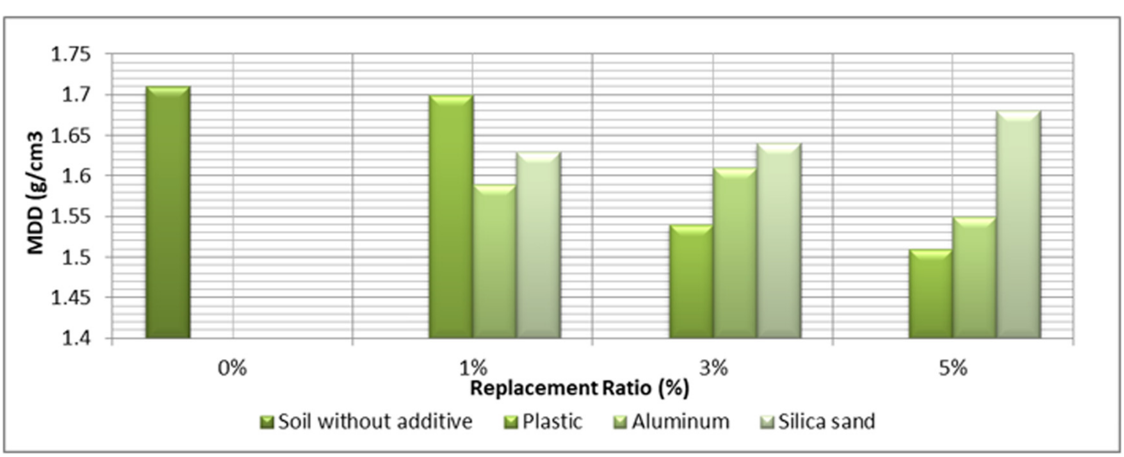


Figure 8: Soil samples maximum dry density and waste material percentage relationship.

Table 2: Test results of the soil sample incorporated with waste material for maximum dry density and optimum moisture content

Waste material	Soil description	MDD (cm^3/g)	OMC%
Plastic waste	Soil without additive	1.71	22.63
	Soil with 1% plastic	1.70	16.19
	Soil with 3% plastic	1.54	26.10
	Soil with 5% plastic	1.51	14.10
Aluminum waste	Soil without additive	1.71	22.63
	Soil with 1% aluminum	1.59	26.10
	Soil with 3% aluminum	1.61	26.40
	Soil with 5% aluminum	1.55	27.90
Silica sand	Soil without additive	1.71	22.63
	Soil with 1% silica sand	1.63	18.00
	Soil with 3% silica sand	1.64	23.40
	Soil with 5% silica sand	1.68	19.70

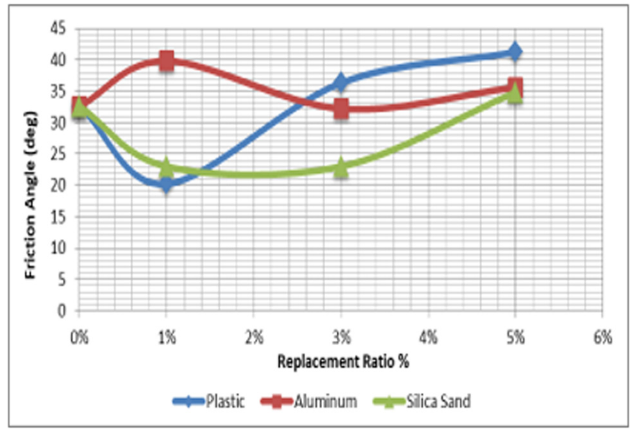


Figure 10: Friction angle (Φ) and percentages of waste relationship.

water content were used for each of the previously used samples in the compaction test in preparing the sample for this test, samples having a volume of 60 mm × 60 mm × 20 mm were prepared, and the applied stress was 1.25 mm per minute; Figure 9 shows a picture of the direct shear test device used. Figures 10–13 show the results of this test.

Through the previous figures and Table 3, after applying plastic and silica sand, we observed a rise in the value of the interior friction angle and a rise in the percentage, and this was close to what was found in the research of Nsaif [13]. From this research, we noticed an increase in the angle of internal friction of the soil when adding plastic and aluminum wastes in most of the added percentages, as it increased by 11.34 and 26.41% when adding 3 and 5% of the plastic waste material, respectively. In addition, the rate of increase was 22.09 and 9.23% for the ratios of 1 and 5, respectively, for aluminum waste. However, the increase was 6.84% for the silica sand when adding 5% of the plastic waste material. As a result, the aluminum and plastic waste materials had more influence on the friction angle, perhaps due to the increase in surface area of these two materials, which is more than the surface area of the

Figure 9: Direct shear test device.

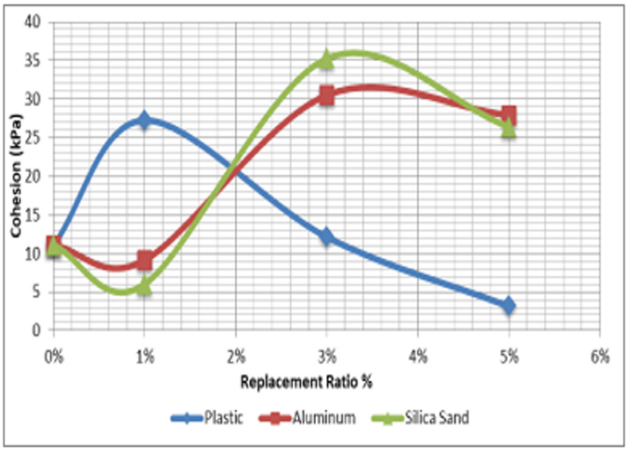


Figure 11: Cohesion (*C*) and various percentages of waste relationship.

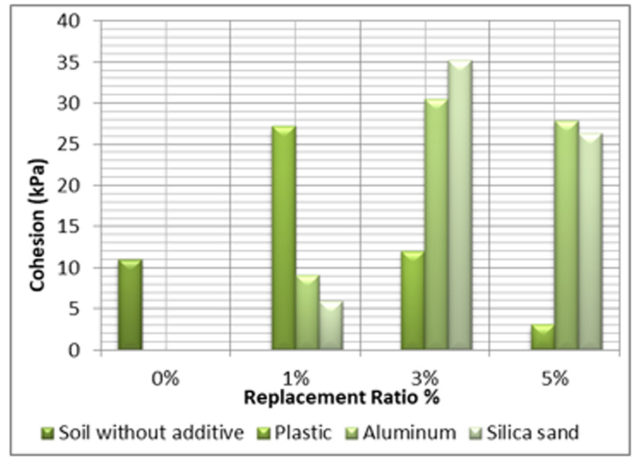


Figure 13: Variation of soil cohesion due to percentages of three waste materials.

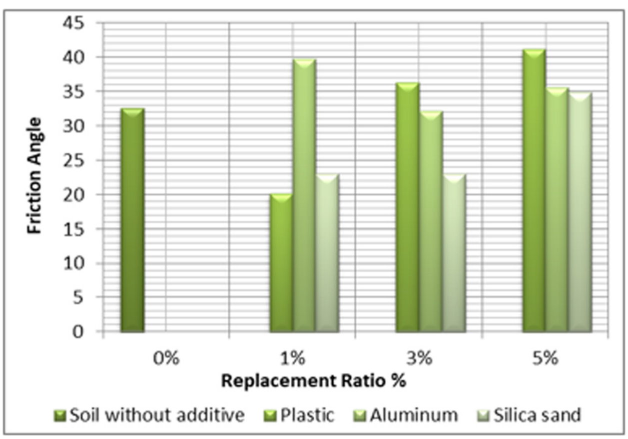


Figure 12: Variation of angle of friction due to various percentages of three waste materials.

soil particle, compared with the silica sand material, which has a similar size to the soil particle. As for cohesion, it is also possible to notice an increase in cohesion when 1 to 3% plastic material is added: the increases in cohesion were 146.35 and 9.47%, respectively. When adding aluminum and silica sand, the increase was clear at a ratio of 3 and 5% for both materials: for aluminum, it was 175.94 and 152.42% for each of the 3 and 5%, respectively, and for silica sand the increase was 218.7 and 138.4% for each of the 3 and 5%, respectively. This test's outline was similar to what Hamid [15] discovered in his research. According to the aforementioned results, the best percentage for each of the additives is plastic material at 3%, aluminum at 4%, and silica sand material at 5%, which is affected by increasing cohesion

Table 3: Results of direct shear test on the soil mixes with waste materials

Waste material	Soil description	Angle friction *Φ*	Cohesion *C* (kPa)
Plastic waste	Soil without additive	32.60	11.053
	Soil with 1% plastic	20.20	27.23
	Soil with 3% plastic	36.30	12.10
	Soil with 5% plastic	41.21	3.13
Aluminum waste	Soil without additive	32.60	11.053
	Soil with 1% aluminum	39.80	9.10
	Soil with 3% aluminum	32.20	30.50
	Soil with 5% aluminum	35.61	27.90
Silica sand	Soil without additive	32.60	11.053
	Soil with 1% silica sand	22.98	6.00
	Soil with 3% silica sand	23.00	35.23
	Soil with 5% silica sand	34.83	26.38

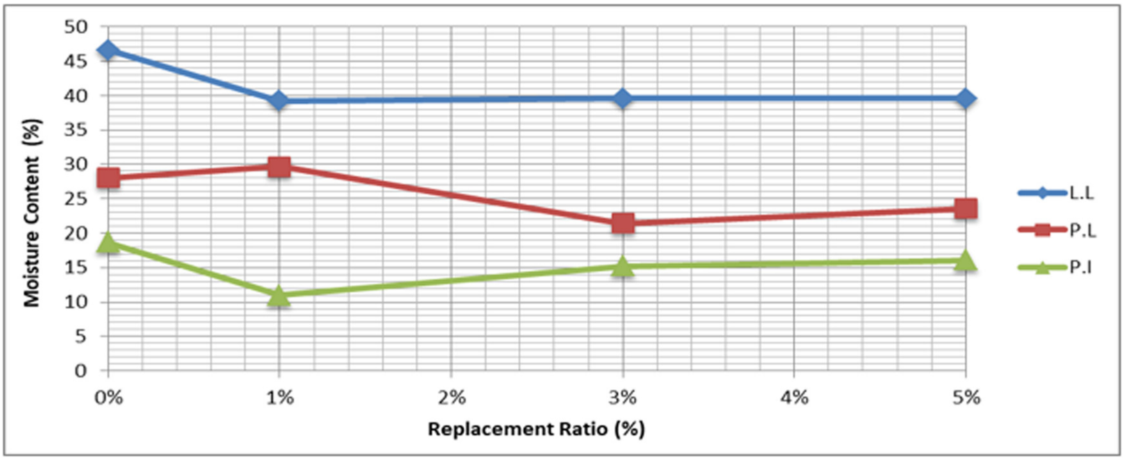


Figure 14: Effect of silica sand on consistency limits.

and angle of friction and thus increasing the shear resistance of the soil.

3.3 Consistency limits

The results of LL, PL, and PI with varying percentages of silica sand are shown in Figure 14. It can be seen from this figure that LL was decreased with the increase in the percentage of silica sand. On the other hand, PL was slightly increased when 1% of silica sand was added; the values were gradually decreased when the percentage of silica sand was increased. This affects the value of PI, transforming the soil from high plasticity to medium plastic soil [17]. The decrease in the value of PI was 42.11, 21.05, and 15.78% for each of the 1, 3, and 5%, respectively. This could be due to the activity of silica sand during hydration. This decrease leads to a decrease in the compressibility and swelling of the soil; hence, this soil can be used to improve the soil subgrade.

4 Conclusions

The test findings presented in this study demonstrate how silty sand reacts to different amounts of waste materials.

1. MDD decreases with the increase in percentage of all waste materials (plastic waste, aluminum waste, and silica sand) that were added to the silty sand soil and the maximum value of decrease was at 5% additive from plastic waste material.
2. OMC decreases by 28.45% due to 1% plastic waste addition. While OMC decreases by 20.45% and 12.45% due to 1% and 5% silica sand addition respectively.
3. The amount of additional material increases as the specified maximum weight decreases.
4. In general, as the amount of additive material increases, the degree of frictional resistance also increases.
5. The best percentage for plastic waste, aluminum and silica sand additives for soil cohesion and soil friction angle improvement were 3%, 5% and 5% respectively.
6. Increasing the addition of silica sand waste led to a decrease in the plasticity (PI) and this decrease leads to a decrease in the compressibility and swelling of the soil; hence, this soil can be used to improve the soil subgrade.

Conflict of interest: The authors state no conflict of interest.

Data availability statement: Most datasets generated and analyzed in this study are comprised in this submitted manuscript. The other datasets are available on reasonable request from the corresponding author with the attached information.

References

[1] Imariq SM, Abdul-Sahib AA, Saleem HD, Shamkhi MS. Quantify distribution of topsoil erodibility factor for watersheds that feed the Al-Shewicha trough–Iraq using GIS. Open Eng. 2022;12(1):769–77.
[2] Shamkhi MS, Al-Badry HJ. Soil texture distribution for east wasit province, Iraq. In IOP Conference Series: Earth and Environmental Science. Vol. 961. IOP Publishing; 2022. p. 012073.
[3] Hassan HJA, Rasul J, Samin M. Effects of plastic waste materials on geotechnical properties of clayey soil. Transp Infrastruct Geotechnol. 2021;8(3):390–413.

[4] Consoli NC, Montardo JP, Prietto PDM, Pasa GS. Engineering behavior of a sand reinforced with plastic waste. J Geotech Geoenviron Eng. 2002;128(6):462–72.
[5] Naeini SA, Sadjadi SM. Effect of waste polymer materials on shear strength of unsaturated clays. Electron J Geotech Eng. 2008;13(Bund. K):1–12.
[6] Zuheir K, Ali FC, Nurullah A. The Behavior of Clayey Reinforced with Waste Aluminum Pieces. Procedia Earth and Planet. Sci. 2015;15:353–8.
[7] Karabash Z, Çabalar AF, Akbulut N. The behavior of clayey soil reinforced with waste aluminium pieces. Procedia Earth Planet Sci. 2015;15:353–8.
[8] Wang F, Feng X, Gong H, Zhao H. Study of permeability of glass-sand soil. Arch Civ Eng. 2017;63(3):175–90.
[9] Syed AJ, Sudipta C. Effect of Waste Glass Powder on Subgrade Soil Improvement. Int. Sci. J. 2020;144:30–42.
[10] Javed SA, Chakraborty S. Effects of waste glass powder on subgrade soil improvement. World Sci News. 2020;144:30–42.
[11] Małek M, Łasica W, Jackowski M, Kadela M. Effect of waste glass addition as a replacement for fine aggregate on properties of mortar. Materials. 2020;13(14):3189.
[12] Hassan H, Rasul J, Samin M. Effects of plastic waste materials on geotechnical properties of clayey soil. Transp Infrastruct Geotechnol. 2021;9(8):390–413.
[13] Nsaif MH. Behavior of soils strengthened by plastic waste materials. J Eng Sustain Dev. 2013;17(4):182–94.
[14] Dixit S. Effect of waste plastic on the strength characteristics of the subgrade for the flexible pavement. GRD J-Global Res Dev J Eng. 2017;2(11):19–33.
[15] Hamid A. Use of waste plastics for the enhancement of soil properties: a recent advancement in geotechnical engineering. Int J Eng Res Technol. 2017;6(7):102–11.
[16] Kadhim YM, Al-Adhamii RA, Fattah MY. Geotechnical properties of clayey soil improved by sewage sludge ash. J Air Waste Manag Assoc. 2022;72(1):34–47.
[17] Murthy V. Textbook of soil mechanics and foundation engineering-geotechnical engineering series. New Delhi: Pvt: Statish Kumar Jain; 2007.