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Sustainable Potentials of Plastics Waste-cement Kiln Dust Blends on Strength Properties of Subbase Soil

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Abstract
There are large deposits of waste materials from various industrial or building activity all over the world. Out of this enormous quantity of waste, a little amount gets recycled, while the rest is dumped in vulnerable places. This paper examines the potential use of waste materials in subbase, including recycled chips derived from waste polyethylene terephthalate plastics and cement kiln dust resulting from Portland cement industry as by-product. Samples were formed by blending fractions of 0, 4, 6, and 8% recycled chips with or without 3% cement kiln dust (CKD) by the required weight of subbase soil. The influence in terms of strength was evaluated using CBR values, which exhibited descending values with increasing recycled plastics chips contents. While the addition CKD significantly enlarged the values. Based on the CBR values 4% recycled plastics chips with 3% CKD blend is commended for subbase layer in roads construction.

Keywords
California Bearing Ratio, soil stabilization, pozzolanic material, sustainable, waste

1 Introduction

Reducing the amount of waste materials disposed of is the primary objective of trash recycling, which has an adverse effect on the environment. Recycling of waste materials has also been used to provide substitute materials that encourage the slow decline of natural resources, which are being overused [1–6] In most places around the country, flexible roadway is the desired kind of pavement for roads and highways. However, creating and maintaining these types of structures requires a significant amount of non-renewable resources and industrial products, including bitumen, aggregates, subbase, cement, lime and other additives. It is unsustainable to manufacture and remove that many virgin building materials at once [7–12]. Depletion of natural resources wasted materials, destruction of the environment, and an increasing in cost of materials have all prompted scientists to create recycled products that may be used for producing of flexible roadway. Likewise, plastics manufacturing has expanded substantially during the previous 60 years, and existing stages of use and discarding cause a number of environmental issues. Landfill is the traditional method of waste disposal, but as the volume of non-biodegradable waste grows, landfill space is becoming rare. Plastics recycling can therefore assist to reduce the environmental effect of the sector while also reducing resource depletion [13–16]. Polyethylene terephthalate thromboplastic is among the utmost often employed polymers for food packing, subsequent in a variety of short-lifecycle objects that are discarded by consumers. Due to slow polymer breakdown, non-recycled plastic components of this sort wind up in landfills or are spread in the environment, generating a variety of environmental hazards [15, 17, 18].

Jaber et al. [19] investigated the outcome of the addition of recycled waste plastic on subbase strength characteristics. Five proportions of recycled polyethylene terephthalate plastic granules with cylindrical form, 2.5 diameter, and 4 mm height, ranging in volume from 2.5 to 12.5 percent. According to the findings, the addition of plastic waste granules intensely changed the performance of the subbase. The rising presence of waste plastic granule in California bearing ratio varied from 6% to 36%. They propose 10% waste plastic granules as optimal proportion.

Majid et al. [20] used the domestic plastic waste fibers and Portland cement in subbase layer of flexible road pavement. Two fractions of fibers (0.5 and 1.0%) made from

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shredded low-density polyethylene water bottles with 10 mm long and 5 mm wide, and 5% of cement of the total dry weight utilized. They found that utilizing the plastic fibers with small quantity of cement as binding material help to strengthening and stabilizing the subbase layer in roads construction works.

Gangwar and Tiwari [21] investigated the impact of shredded waste plastic bottles on soil characteristics. Various experiments were carried out using 0%, 0.5%, 1%, 1.5%, and 2% of 4.75 mm maximum size shredded waste plastic. The findings of this study revealed that the addition of waste plastic bottles has a positive effect on soil properties, promoting the re-use of waste plastic from industry in a cost-effective and sustainable manner, and it will also assist with the disposal problem of these plastic wastes to some extent.

Mahdi et al. [22] examined at the potential of using cement kiln dust to enhance the properties of sand-gravel soil. Soil samples treated with 5%, 10%, 15%, or 20% of cement kiln dust as weight replacement. They discovered that adding 20% cement kiln dust to type (B) subbase soil raised the shear strength, CBR value, density and optimum moisture content.

Salih et al. [23] conducted an experimental study for stabilizing of expansive soil by utilizing polypropylene plastics waste and cement kiln dust. The waste materials were added to expansive soil at fractions ranged from 2% to 20%. The best percentages of polypropylene plastics waste and cement kiln dust, according to the results, are 12 percent for each. With the addition of a combination of both polypropylene plastics waste and cement kiln dust, Liquid Limit, plastic limit, and swelling percent loss were detected, which are respectively 46, 55, and 96 percent, and a California Bearing Ratio increase of 98 percent was attained.

Saeed et al. [24] examined the effect of reclaimed asphalt pavement (RAP) and cement kiln dust (CKD) on subgrade soil properties. Four percent reclaimed asphalt pavement up to 35% with four percent cement kiln dust up to 20% were investigated for some subgrade soil properties. The authors observed that utilizing the RAP–CKD blend largely improved strength properties of clay subgrade layers. The optimum addition 25% RAP with 20% CKD.

As a result, it was agreed that the goal of this study would be subbase soils that could be stabilized by different by-product or waste substances. Subbase soil was chosen to be treated with CKD and recycled waste plastic chips individually and in combination in order to enhance the undesirable geotechnical qualities and preserve environmental sustainability by using readily accessible wastes in an economical manner. This study is unique in that it takes into account both CKD and recycled waste plastic chips with high level of addition simultaneously (which has not been adequately done in previous studies in the field. The obtained contribution will be presented in the findings section that follows.

2 Constituents and methodology

2.1 Constituents

Three basic constituents were utilized in existing study: subbase soil, waste plastic material (PET), and cement kiln Dust (CKD). Subbase soil was acquired from one of Karbala province quarries and it was measured for its gradation and physical properties. The subbase soil was classified as subbase grade B agreeing with the Iraqi General Specification for Roads and Bridges for Subbase requirements (R6). Table 1 displays some of the physical characteristics of the utilized subbase soil, and Table 2 displays the results of sieve analysis test. The grain size distribution curve is shown in Fig. 1.

Waste plastic material used for this study is recycled Polyethylene Terephthalate (PET). These waste materials are recycled as cylindrical small chips of size ranged between 2-6 mm length (as shown in Fig. 2) by a local recycling factory in Kerbala province. While the Cement Kiln Dust (CKD) is a fine, powdery material (shown in Fig. 3), which contains a portion of reactive calcium oxide.

Table 1 The physical properties of the raw subbase soil

Subbase properties	Value
Max. Dry Density gm/cm^3	2.16
Optimum Moisture Content %	7.2
Liquid limit %	N.P.
Plastic Limit %	N.P.
Plasticity Index	N.P.
Total Soluble salt %	3.77

Table 2 Sieve analysis results

Sieve no.	Diameter (mm)	percentage of passing %	Iraqi General Specification (Type B)
2"	50.8	100	100
1"	25.4	81	75–95
3/8"	9.50	53	40–75
4	4.75	42	30–60
8	2.36	38	21–47
50	0.3	15	14–28
200	0.075	7	5–15

CKD was used in this study as binder (stabilizer) material and it was collected from a cement factory located in the Al-Nkheeb, in Al-Anbar province.

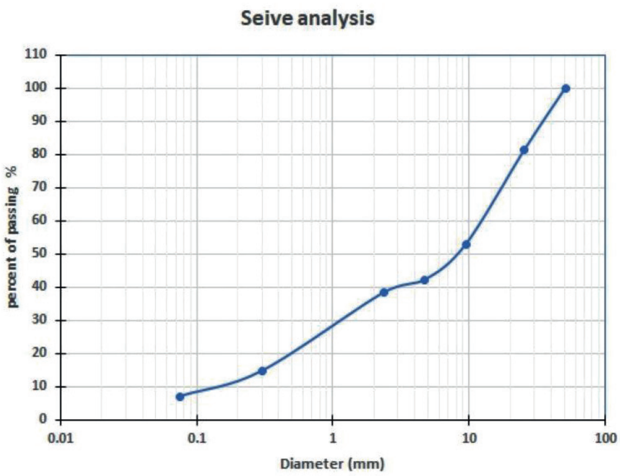

Fig. 1 Particle size distribution curve for the subbase soil

Fig. 2 Recycled waste plastic chips

Fig. 3 Cement kiln dust (CKD)

2.2 Methodology

2.2.1 Compaction tests

Modified Procter Test procedure was used in this study to obtain the maximum dry density (MDD) and optimum moisture content (OMC) of raw and stabilized subbase soil. The test was conducted with accordance to the American Specifications ASTM D 1577 [25]. The aim of conducting this test was to identify weather the addition of the waste plastic chips and the CKD affect the compressibility properties of the soil to use the OMC to prepare the specimens for the CBR test. The test was first carried out on a control mixture with no additives (0% plastic + 0% CKD), and then different percentages of PET chips were added to the subbase soil (4%, 6%, 8% by weight of subbase) as specimens were prepared and subjected to Modified Procter test. Then, a constant percentage of 3% of CKD was added to each subbase + PET mixture. (4%PET+3%CKD, 6%PET+3%CKD, 8%PET+3%CKD) and tested with Modified Procter test.

2.2.2 California Bearing Ratio (CBR)

The California Bearing Ratio (CBR) test is just a penetration process that employed to measure the prospective strength of base coarse, subbase, and subgrade material, incorporating recyclable materials. The findings are applied to the pavement design for roadways and airports. After performing compaction tests on a series of subbase soil specimens with altered fractions of PET with and without CKD inclusions, other samples with same PET and CKD inclusions were prepared and subjected to the CBR test. Samples were prepared with the OMC and MDD obtained from the compressibility tests conducted in the prior stage and soaked in water tank for 4 days. Then each sample was tested by using CBR compression machine, which applies load by a standard circular piston of 1935 mm^2 cross section area with a rate of 1.27 mm/min. CBR values then calculated by dividing the load value obtained at 2.5 mm or 5 mm penetration of the piston into the soil (whichever higher) on the standard load value of crushed stone corresponding to the same penetration. CBR test was carried out according to the American specification ASTM D-1883 [26] (Standard test method for California bearing ratio (CBR) of laboratory-compacted soils).

3 Results and discussion

3.1 Outcome of waste plastic and CKD on compaction

The summary of the compressibility test results; optimum moisture content (OMC) and maximum dry density (MDD) is shown in Figs. 4 and 5. It can be noticed from these

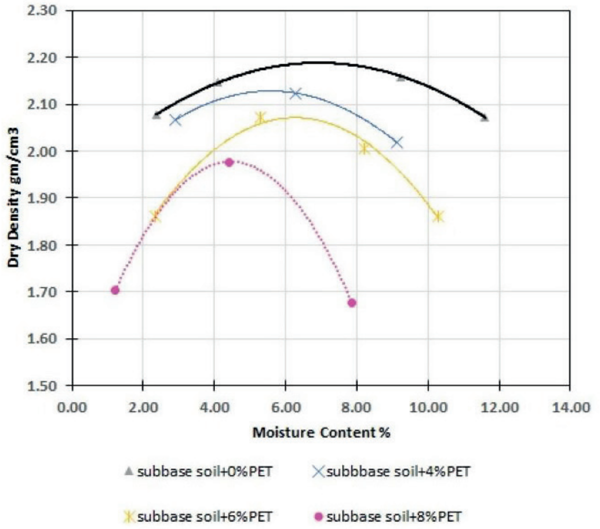

Fig. 4 Compaction curves for subbase and PET only

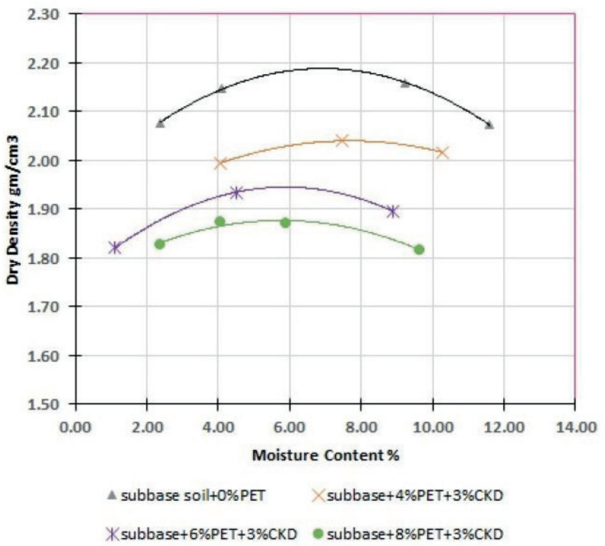

Fig. 5 Compaction curves for subbase and PET + CKD

results that for identical compaction energy, as the proportion of waste PET chips increases, the OMC decreases, this was expected because of the low moisture absorption properties of the plastic chips, which leads to decrease the water content.

The decrements of OMC were about 11%, 18%, and 37% for 4%, 6%, and 8% PET percentages by weight when compared with subbase without plastic, respectively. Furthermore, the combined effect of CKD and PET on the values of OMC was about 10% increment for 4% plastic with CKD, while, the combined effect of CKD and PET on the values of OMC were about 15% and 32% decrement for 6% and 8% PET percentages by weight with CKD when compared with subbase without plastic, respectively. This can be attributed to the ability of CKD to water absorption by the pozzolanic reaction which leads to absorb more water thus increase the OMC. This is also consistent with what was mentioned by (Attah et al. [27]).

Moreover, the results show that the MDD decreases with the addition of plastic chips, and when adding CKD to the mixtures. The decrement values of MDD were about 1.8%, 3.7% and 8.3% for 4%, 6%, 8% PET when compared with subbase without plastic, respectively. The decrement values of MDD were about 5.5%, 10.1% and 12.9% for 4%, 6%, 8% PET with CKD when compared with subbase without plastic, respectively. This was expected because the unit weight of PET material is less than that for subbase, so that addition of this material leads to decrease the weight per unit volume, which means decrease the density of subbase soil.

Figs. 4 and 5 show the compaction curves obtained from the laboratory experiments. Figs. 6 and 7 show a comparison between the variation of MDD and OMC with different percentages of PET waste plastic and CKD, respectively. This trend somewhat was reported by earlier authors [28, 29].

3.2 Outcome of waste plastic and CKD on CBR

The value of California Bearing Ratio (CBR) of subbase is considerably altered by incorporation of the waste plastic chips as shown Fig. 8. The results show a reduction in CBR values for the subbase soil when incorporation diverse fractions of PET, as exhibited in Fig. 8. The decrement of CBR values about 31%, 50% and 81% for 4%, 6% and 8% PET when associated raw subbase. Whereas these values improved by adding 3% of cement kiln dust (CKD) as a binding material. The increment of CBR values about 60%, 51%, and 247% for 4%, 6% and 8% PET when likened with relative mixes with CKD, respectively.

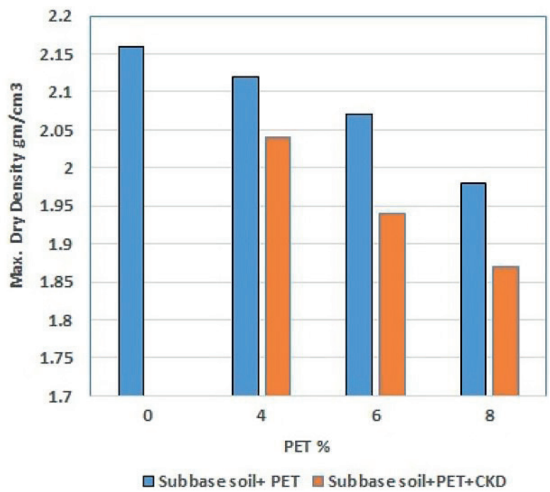

Fig. 6 Relationship between MDD with different percentages of PET+3%CKD inclusion

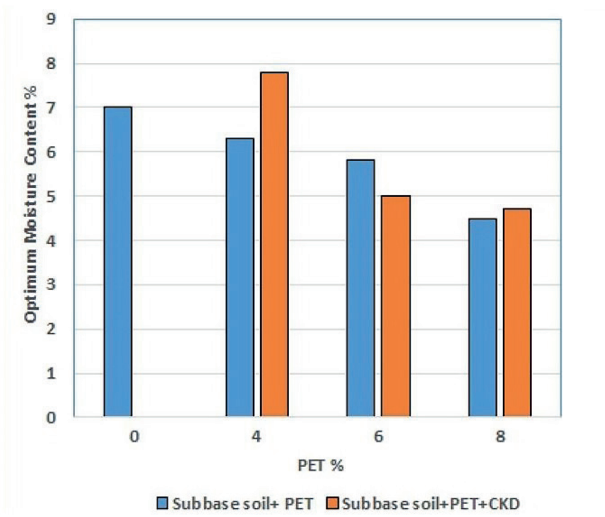

Fig. 7 Relationship between OMC with different percentages of PET+3%CKD inclusion

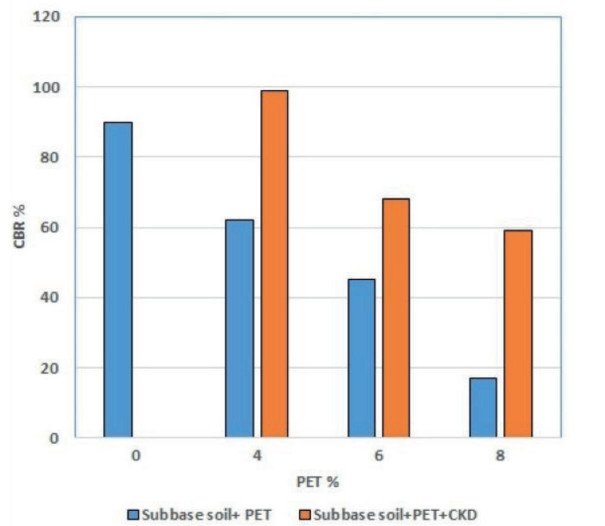

Fig. 8 Relationship between CBR values with different percentages of PET+3%CKD inclusion

This is attributed to the CKD reaction which forms bonds and tightens the soil structure by the pozzolanic reaction. Thus, CKD works like a cement which gives a strength to the subbase-PET mixtures so that resulting in increasing soil resistance as shown in Figs. 9 to 11 by the load-penetration curves. These curves show that soil resistance decreases by adding PET only, but it increases when adding 3% CKD. The maximum resistance can be attained by adding 4% Plastic with 3% CKD.

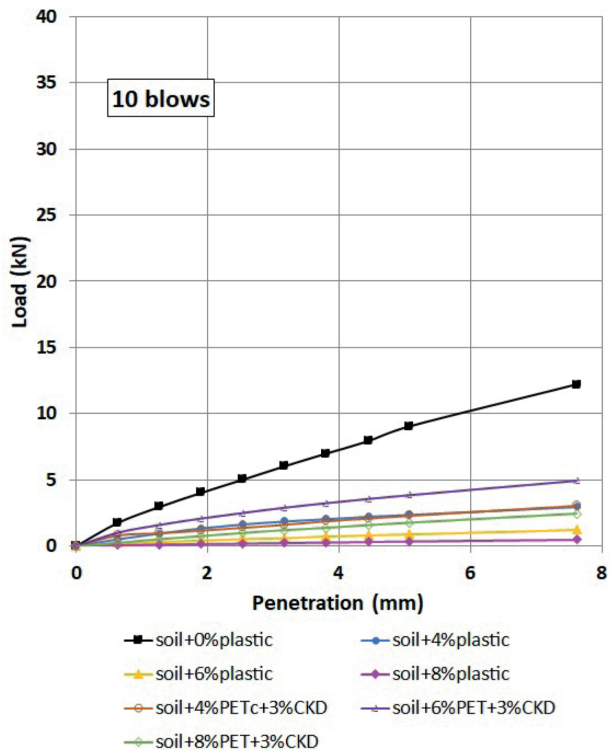

Fig. 9 Relationship of load with penetration for 10 blows

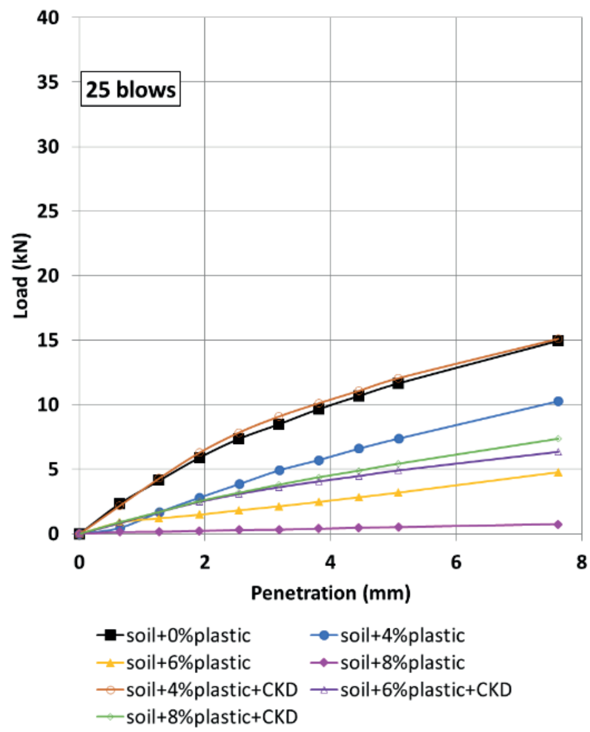

Fig. 10 Relationship of load with penetration for 25 blows

4 Conclusions

After completing the experimental work on concurrently substituting recycled waste plastic chips and CKD by weight of subbase soil and their thorough investigation, the following conclusions could be drawn:

1. As recycled plastic chips content increase in the modified subbase, OMC decrease. However, the addition of CKD with plastic increases the OMC when compared with corresponding percent of plastic.

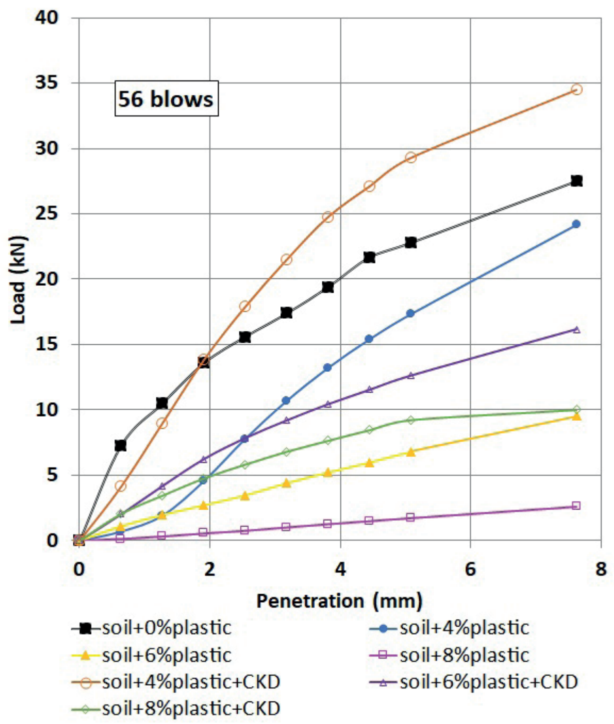

Fig. 11 Relationship of load with penetration for 56 blows

2. MDD decreases as the recycled plastic chips fractions in modified subbase increases. In addition, when CKD joint with plastic, the MDD decreased slightly when compared to the comparable percentage of plastic.
3. The addition of the recycled plastic chips in the modified subbase significantly reduced the CBR values. The reduction percent range from 31% to 81%.
4. The insertion the CKD with the recycled plastic chips in the modified subbase considerably increased the CBR values. The improvement percent range from 50% to 247% when compared with associated percent of plastic.
5. Due to the largest improvement in the CBR value of modified subbase, the ideal replacement percentage for waste materials in modified sustainable subbase is 4% Plastic with 3% CKD.
6. There is potential for recycling waste materials such as waste plastic and CKD to partially replacement from subbase in the production of modified sustainable subbase.

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