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INVESTIGATE THE EFFECT OF PAPER SLUDGE ASH ADDITION ON THE MECHANICAL PROPERTIES OF GRANULAR MATERIALS

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Abstract: Ignition of waste paper sludge at elevated temperatures to produce electricity in power generation plants utilizing fluidized bed combustion generates paper sludge ash. Due to the high concentration of lime and gelignite in paper sludge ash, it is expected that it will play a vital role as a cementitious material. This paper investigates the use of paper sludge ash to improve the mechanical properties of the granular materials, which are suitable to subbase course for road and building constructions. Also, a comparison study with the use of Portland cement as an additive to granular materials has been covered. The mechanical properties were evaluated by conducting the California bearing ratio test for the two adopted methods. Moreover, the compressive strength of the samples using paper sludge ash and cement are investigated. In accordance to the California bearing ratio test, 4% paper sludge ash was indicated as the optimum ash content at which the California bearing ratio value increased by 173% and 111% in comparison with untreated material and 6% cement, respectively. On the other hand, and by means of the compressive strength, the granular materials with 4% paper sludge ash has compressive strength higher than those with 6% cement.

Keywords: Compressive strength, California bearing ratio test, Paper sludge ash, Cement, Granular material

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1. Introduction

1.1. General

In all construction projects the main goal of engineers is to construct a structures, highways, roads etc. able to resist the applied loads and environment conditions. If the soil under structure, which cannot resist, the applied load must be treated to improve its performance and give the required strength. One of the guides to measure the soil strength to bear applied loads is California Bearing Ratio (CBR), which is defined as the penetration test calculates the mechanical strength of base, subbase and subgrade soils under new carriageway construction. California Department of Transportation introduced this test before World War II.

Many previous studies as [1], [2] have been conducted to investigate the influence of adding supplementary cementitious materials i.e. fly ash, slag, silica fume to the different type of concrete.

[3] studied the gain from adding fly ash material in the CBR for many types of soils at Botswana country; the soils included clayey soil, sandy soil and silty sand soil. The fly ash material was brought from the only power station in Morupule, which is produces about 350 tons of fly ash as a waste material. The effect of use of fly ash as an improvement additive on CBR was investigated. The results showed that the CBR increase for all used soils except for sand of Kalahari, which first decreases and after 16% fly ash increases. The results also conducted that the increase in CBR for silty sand soil is maximum and for black cotton soil is minimum. The researcher recommended that the silty sand, silts and calcrete of medium and low plasticity can be used for base courses by stabilizing with fly ash.

[4] studied the CBR of waste plastic strip-reinforced stone dust/fly ash overlying saturated clay. The effect of the length and (0.25% to 4%) of different sizes of waste plastic strips on CBR and secant modulus of strip reinforced-stone dust/fly ash overlying saturated clay was investigated were investigated. The study showed that modified soils i.e. with waste plastic strip, increase noticeably the CBR and the secant modulus. Also, addition of waste plastic strips more than 2% does not develop the CBR or secant modulus significantly.

[5] introduced a study to investigate the addition of lime and fly ash on CBR of locally soil of National Institute of Technology Agartala campus in India. The results showed that the CBR value of the soil with fly ash and lime increases when the fly ash and lime increase, also the soil-lime mix CBR value has a higher value comparing with the soil- fly ash mix even with small lime percentages in soil.

[6] added two types of fly ash (FA1 and FA2) to a silty clay soil collected from the shoulder of the River Alt, which is located in High Town to the north of Liverpool City Centre in the United Kingdom. The two types of fly ash are a waste material brought from two industries in UK. The particles of FA1 are coagulated in shape and some spherical and FA2 were irregular in shape. The enhancement levels were assessed based on the results attained from compaction tests, consistency limits and Unconfined Compressive Strength (UCS) tests, which were made on samples of soil treated with FA1 and FA2 and exposed to several curing periods i.e. 0, 7, 14, and 28 days. They indicated that FA1 and FA2 efficiently enhanced the geotechnical and physical

properties of the soft soil where the Plasticity Index (PI) has been reduced considerably from 21 to 13.17 with 12% of FA1; however, there was a slight increase in IP with the use of FA2. So, they identified that 12% of FA1 as the optimum percentage due to significant improvement on the UCS of stabilized soil. Moreover, FA2 was found active as a chemical activator to FA1 where the UCS was enhanced considerably after using FA2.

[7] studied the of Ground Granulated Blast furnace Sludge (GGBS) and GGBS-lime mixes effect on the improving CBR of expansive soil. The used GGBS ratios were 3, 6, 9 and 12% respectively in the mixes of GGBS-soil mixes while 2 parts of GGBS and 1 part of lime were used for 3, 6, 9, and 12% in GGBS-lime mixes. The conclusions were that the CBR varies from 6% - 31% in GGBS-soil mixes and 22% - 48% in GGBS-lime mixes, this can be indicated that the use of lime as additive to the GGBS gave a superior binder.

1.2. Scope of study

Incineration of waste paper sludge at elevated temperatures to produce electricity in power generation plants utilizing fluidized bed combustion generates Paper Sludge Ash (PSA). It is estimated that PSA will play a vital role as a cementitious material due to the high concentration of lime and gelignite. On the other hand, because of the problems, which are occurred in the subbase layer in roads and buildings in Iraq, many ways can be adopted to improve the strength and durability of subbase material. This paper presents a lab investigation to study the effect of adding PSA on the mechanical properties of granular materials, which conventional used as a subbase course used in roads, highways pavements, buildings etc. Also his paper presents a comparison study with the use of Portland cement as an additive to granular materials. The mechanical properties have been evaluated by conducting the CBR test at the maximum dry density and optimum moisture content for the two adopted method. Also, the compressive strength of the samples using PSA and cement are investigated

2. Materials

2.1. Subbase coarse granular material

The granular material used in this research was brought from a place called a quarry region placed in Al-Najaf Governorate, Iraq. The experimental testing was conducted to investigate the chemical, physical and engineering properties of the used soil. The sieve analysis results of the granular material as it is shown in *Fig. 1*. As per the sieve analysis test these material is classified as class C according to the Standard Commission for Roads and Bridges (SCRB) in Iraq. *Table I* presents the physical and chemical properties of the collected sample with the corresponding testing method.

2.2. Cement

In this study, the used cement is collected from a local Kerbala Cement Plant. The type of cement is sulfuric salts resisting. The samples of used cement were tested in the laboratory of Engineering Consulting Bureau-Faculty of Engineering-University of Kufa. The chemical and physical properties of cement are shown in *Table II*-Table III and *Table IV*, respectively.

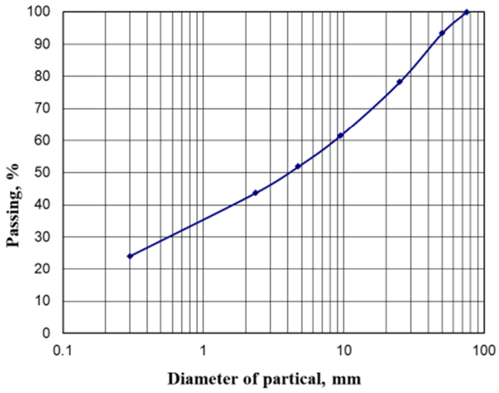


Fig. 1. The grain size distribution of the granular materials

Table I

Physical and chemical properties of the granular material

Property	Test Method	Results
Liquid limit, %	ASTM D423, [8]	34.8
Plasticity index, %	AASHTO T90, [9]	12
Organic materials, %	BS 1377, No. 3, [10]	1.2
SO_3 salts, %	BS 1377, No. 3	0.08
Optimum Moisture Content (OMC), %	AASHTO T180, [11]	7.1
Maximum Dry Density (MDD), kN/m^3	AASHTO T180	21.1
CBR	AASHTO T193, [12]	34.9

Table II

Chemical properties of used cement I

Oxide	Content, %	Limits according to IQS No.5/1984
iO_2	21.42	------
MgO	1.78	$\leq$ 5%
Fe_2O_3	5.90	-------
CaO	63.75	-------
SO_3	2.15	$\leq$ 2.5%
Al_2O_3	3.04	-------
Free lime	1.52	$\leq$ 4%
Loss of Ignition	1.21	$\leq$ 4%
Insoluble Residue	1.30	$\leq$ 1.5%
L . S . F	0.90	0.66 – 1.02

Table III

Chemical properties of used cement II

Main compounds (Bogue's equation)	% by wt. of cement
C_3S	55.55
C_2S	19.50
C_4AF	17.95
C_3A	0

Table IV

Physical properties of used cement

Physical properties	Test results	Limit of Iraqi specification IQS No.5/1984
Setting Time, min Initial Final	 150 275	 ≥ 45 min ≤ 600 min
Fineness, Blain method In cm^2/gm	 2810	 ≥2500
Compressive strength: in MPa at 3 days 7 days	 18.3 28.3	 ≥ 15 ≥ 23

2.3. Paper sludge ash

PSA is resulted from the combustion of paper sludge between 700 ºC and 1200 ºC in power generation plant using a fluidized bed combustion system. *Table V* shows the chemical analysis of PSA, while *Fig. 2* presents the particle size distribution. Also, *Fig. 3* shows the Scan Electron Microscopy (SEM) photo of PSA.

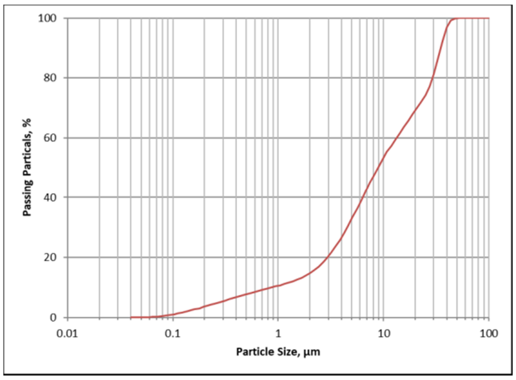


Fig. 2. Particle size distribution of PSA

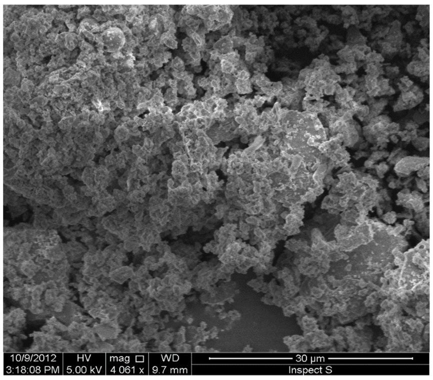


Fig. 3. Scan electron microscopy view of PSA

Table V

Chemical composition of PSA

Element	Concentration, %
CaO	60.58
SiO_2	26.25
Fe_2O_3	0.25
MgO	3.31
Al_2O_3	2.76
K_2O	0.30
Na_2O	1.80

3. Experimental work

The experimental work was divided into two stages, first investigated the performance of the granular material with cement as five percentages have been added to the virgin materials i.e. 0, 1, 2, 4, 6% by mass of soil. CBR were tested to the whole soils i.e. with and without cement. CBR is conducted in accordance to AASHTO T193. Commonly, CBR value affects directly on the strength of base, subbase and subgrade layer strength for roads, which is adopted in by California Department of Transportation, and since then it has been used comprehensively for road design purposes. Primarily it was adopted to describe granular aggregates with sizes ranging between 4.75 mm and 20 mm, recently it has been used for soil materials. The second stage comprised addition of PSA to the soil with different percentages, which were 1, 2, 4 and 6% by mass of the granular material.

3.1. Sample preparation

The OMC and MDD of specified granular material have been achieved according to AASHTO T180 and their values were 7.1 % and 21.1 kN/m^3 respectively as shown in *Table I*. Then, the mass of soil retained on 19 mm sieve has been compensated with equal mass collected from sieving same unused soil passing the 19 mm and retained on 4.75 mm sieve. All samples have been prepared to maximum dry density using OMC equal to 7.1%.

Many laboratory samples were prepared and they were tested in CBR apparatus. Unique sample was tested without adding PSA and cement as reference sample. Five samples were mixed with different percentage of cement and the other five were mixed with different parentage of PSA.

3.2. CBR testing method

CBR test has been used as a standard test to study the effect of additive on the mechanical properties of soil samples and it was conducted according to AASHTO T193 [12]. Five percentages of additives, which were used i.e. 0, 1, 2, 4, and 6%. The water-dry density relationship was drawn to specify the OMC according to AASHTO T180 and the OMC was used to prepare the samples in MDD. Then CBR test was conducted to the samples with and without additives i.e. cements and PSA with OMC. CBR testing machine is shown in *Fig. 4* while the electric compactor is shown in *Fig. 5* which has been used to prepare dry density and CBR test samples.

Fig. 4. CBR test machine

Fig. 5. Compactor apparatus, CBR mold and density mold

3.3. Compressive strength test

In accordance to the Standard Commission for Roads and Bridges (SCRB) in Iraq, the compressive strength of the selected cementitious material percentage shall be 25 kg/cm^2 to 50 kg/cm^2 after storage in a box with minimum humidity 95% for a period of 7 days. The molding was done according to AASHTO T134 and the test procedure according to AASHTO T22. Therefore, the selected percentages in accordance to the CBR test results must be checked for the suitability of the compressive test.

4. Results and discussion

4.1. Compaction test and CBR test of control sample

The compaction test is one of the useful tests that should be carried out to conduct the maximum dry density and optimum moisture content for different types of soil, which are identified as compaction parameters and listed in *Table I*. These parameters vary dependent mainly on soil type. The preparation of the specimens for the experiments to find the other geotechnical properties such as CBR, density, porosity and triaxial test are dependent primarily on the values of OMC and MDD, which are obtained from compaction test.

In this study, modified proctor compaction tests and CBR test were performed on the subbase sample without cement and PSA as a control sample. *Fig. 6* shows the dry density and moisture content relationship for a control sample, from this figure it can be seen that MDD and OMC are 21.1 kN/m^3 and 7.1%, respectively.

CBR test was conducted for the control sample, the relationship between displacement and pressure; as it is shown in *Fig. 7*. The pressure corresponding to the higher value of 2.5 mm and 5 mm displacement divided by mold area gives CBR value of 34.9 as it is listed in *Table I*.

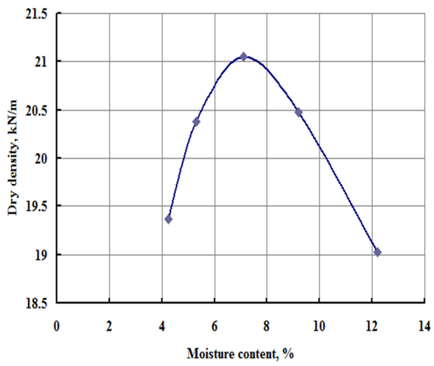


Fig. 6. Dry density and moisture content relationship of control sample

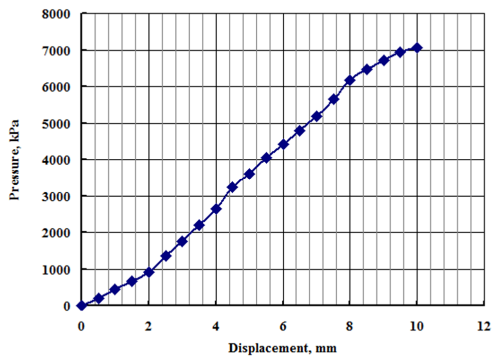


Fig. 7. Displacement and pressure relationship of CBR test for control sample

4.2. CBR test using cement

CBR test was performed using 1, 2, 4, and 6% cement of the total weight of granular material as additive to study its effect on CBR value at OMC. The same procedure as for a control sample was adopted to calculate CBR value. *Fig. 8* shows the relationship between cement percent and CBR for samples with and without cement. From this figure it can be founded that the CBR increase with increase cement percentage.

4.3. CBR test using PSA

The effect of PSA addition on CBR value at OMC was studied practically, the test was performed using fly ash with the percentages 1, 2, 4, and 6% by the weight of granular material. The relationship between PSA percent and CBR is shown in *Fig. 9* while *Fig. 10* shows the CBR results for PSA and cement. From these figures it can be seen that CBR increase up to 4% fly ash then it is decrease at the percentage of 6%. From the results it can be stated that the optimum percentage of using fly ash is 4%, which increases CBR from 34.9 to 95.2 that means the improvement in CBR reaches about 63%.

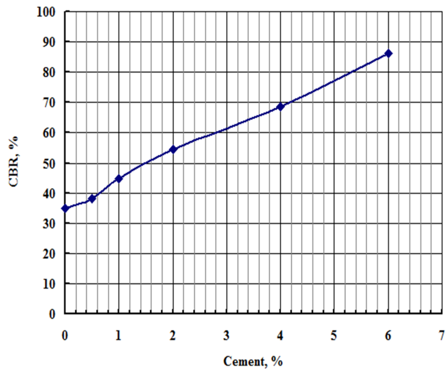


Fig. 8. Relationship between cement percentage and CBR

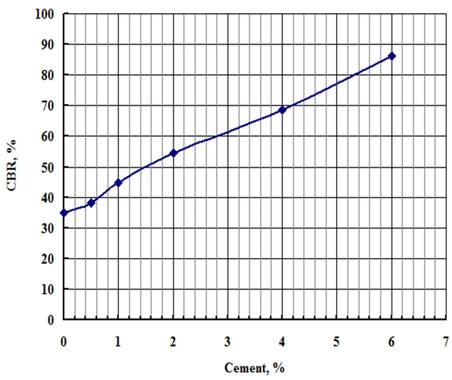


Fig. 9. Relationship between PSA percentage and CBR

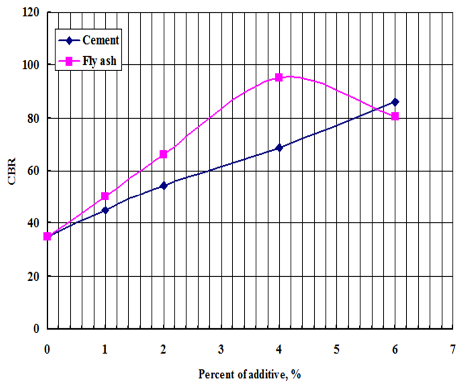


Fig. 10. Relationship between cement and PSA percentages and CBR

4.4. Influence of water content on CBR test results

Because of the higher absorbed characteristic of PSA in comparison with cement, CBR test was conducted for the granular material with 4% PSA with higher than OMC (7.1%) i.e. 8% and 9%, see *Fig. 11*. As it can be seen in this figure, CBR values decreased when water content increased, therefore, it can be concluded that OMC is the most suitable water content and there is no need to increase it due to the high absorption characteristic of PSA.

4.5. Compressive strength results

Compressive strength test has been conducted according to AASHTO T134 for the granular material with different PSA percentages and with 6% cement, (*Fig. 12* and *Fig. 13*). The results shown that the granular material with 4% PSA has compressive strength higher than those with 6% cement by almost 20%.

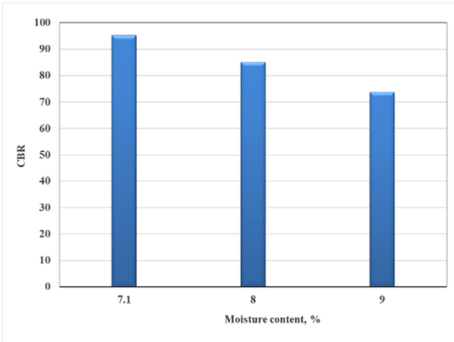
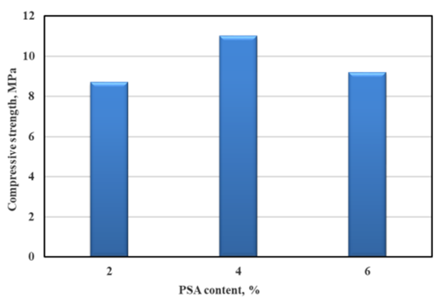


Fig. 11. Influence of water content on CBR values of granular material with 4% PSA



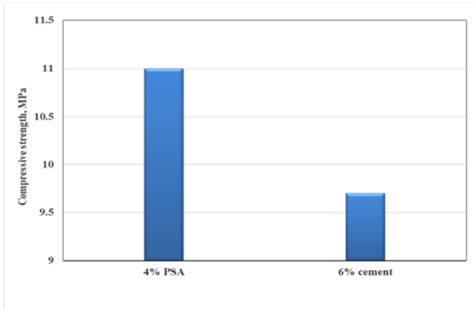


Fig. 12. Compressive strength results for modified granular material with different PSA contents

Fig. 13. Compressive strength results for modified granular material

5. Results analysis

From the laboratory results, it can be concluded that there is a significant increase in CBR value when using cement with sub-base in the construction of roads and structures. From *Fig. 8*, the use of cement increasing CBR about 147% for 6% cement, this improvement in CBR is considered an excellent modification to subbase layer in resisting the loads and gives more durability. The improvement at 2% cement reaches to 56%, which is considered a good percentage of improvement as the required CBR within the acceptable specifications limits and the saving in cement cost is favorite.

On the other hand, CBR increased significantly when PSA (which is classified as waste material) is added. As it is shown in *Fig. 9*, CBR increased until 4% PSA then dropped down, therefore, 4% PSA can be nominated as the optimum PSA content. With this addition percentage i.e. 4% PSA CBR increased 173% in comparison with untreated material and more than those with 6% cement by almost 11%. This can be stated as a significant improvement as PSA (waste material) can be a very attractive replacement to the costly cement material. Also, the new modified material can be used as a base course in a heavily trafficked road. By means of sustainable application, this finding can attribute as another step to achieve the sustainability.

When the granular materials with 4% PSA was prepared with different water contents i.e. more than the OMC (7.1%), CBR decreased. This performance can be attributed to that the OMC is adequate to do the hydration process between PSA and water in addition to the primary role with the granular material which gave the optimum dry density.

Lastly, because the modified granular material has been improved by adding cementitious materials, it is required to check the compressive strength of the new material and investigate its suitability according to the specification. From the results (*Fig. 13*), it is very attractive to see that the compressive strength for the modified granular material with 4% PSA has been increased by about 20%, which can be attributed to the hydration process of PSA with water and the high adsorption of PSA in comparison with cement.

6. Conclusions

This paper investigated the use of PSA and cement individually to improve the mechanical properties of the granular materials, which are suitable to subbase course for road and building constructions. The experimental work performed to investigate CBR of samples using 1, 2, 4 and 6% by mass of granular material for each cement and fly ash and compared with the CBR of the control sub-base course material.

The following conclusions can be drawn from the experimental results:

1. CBR of the modified granular material with 6% cement was improved about 147% in comparison with untreated material;
2. CBR increased significantly with the addition of PSA until 4% (with 173% increase in comparison with untreated material), then it decreased so 4% PSA is named as the optimum fly ash content;
3. At the optimum ash content CBR value increased more than those with 6% cement by about 11%;
4. It can be noted that optimum water content corresponds to the highest mechanical properties as CBR decreased when water content increased more than OMC;
5. By means of the compressive strength, the granular materials with 4% PSA has compressive strength higher than those with 6% cement.

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