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The effect of coal bottom ash as a replacement on subgrade strength

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Abstract. Coal Bottom Ash (CBA) which is one of coal combustion product (CCPs) obtained from thermal power plant will negatively affect the ecological system which human health ultimately depends on. The increase in demands for landfill requirements and the limitations natural aggregates is quite disturbing unless the new alternative to cut the usage of natural aggregates is found. Therefore, this paper present the laboratory investigation work to improve the strength of subgrade by the replacement of CBA with different percentage varies (0%, 15%, 30% & 40%) by weight. California Bearing Ratio (CBR) test is carried out to obtain the optimum percentage replacement CBA and then some physical which are particle size distribution, Atterberg limit test, specific gravity test and compaction test also carried out to observe the mechanical properties of optimum sample. The optimum percentage of CBA replacement obtained is 40.65% at 30% CBA replacement compared to 17.99% of subgrade soil alone. The moisture dry-density of unmodified soil sample is higher (1.99Mg/m^3 , 15.34%) than optimum sample (1.95Mg/m^3 , 10.2%). Moreover, 30% CBA replacement resulted in intermediate plasticity than the subgrade soil which is highly plastic. In conclusion, strength of subgrade soil is highest at 20-30% of CBA replacement.

1. Introduction

In Malaysia, the rapid development as well as rise in population has annually increased the electricity consumption. Thus, the most plentiful and low price energy sources, coal is getting a lot attention. However, Coal Bottom Ash (CBA) which is one of coal combustion product (CCPs) obtained from thermal power plant will negatively affect the ecological system which human health ultimately depends on. Mandal [1] stated when the coal is burnt, the generation of huge amount of ash has become one of the major sources to environmental pollution as well as can be hazardous to human health, this is because heavy metal in CBA for example copper (Cu), mercury (Hg), arsenic (As), cadmium (Cd), and lead (Pb) will stay in the environment as its characteristic that can't be removes or destroyed.

The combustion of coal has caused the increase in ash products and these waste have been a major issues for most of the developing countries. The waste product is practically dumped either in a dry landfill or in ash ponds which also has its shortcomings. Ash pond with 81,000m² area, 2.4m deep situated besides Sejingkat Coal Fired Power Station located in Kuching Sarawak is built and in fact there are two ash ponds with one of them was fully utilized [2]. Tanjung Bin Power Station produces 180 tonnes CBA per day together with 1,620 tonnes fly ash per day from the combustion of 18,000 tonnes of coal alone in a day [3]. It is concerned that the disposal of coal ash has reached its alarming proportion because of the increase coal energy inputs for power generation in 2000 to 2012 by 17.4



TWh to 164.4 TWh significantly. This huge sum proved the massive demand of the coal in Malaysia which leads to building more ash ponds.

Another issues raise is about the critical shortage of natural aggregates (NA) corresponding to the rapidly growth of the construction industry. Weak, unstable and poor subgrade soil has low percentage of California bearing ratio (CBR) which will lead to increase in thickness for pavement layer [4]. This phenomenal is disturbing as the existing of natural aggregates won't be enough to satisfy the future demand, instead of that the escalating cost of natural aggregates in the future must be considered as well. Considering the usage of NA and the landfill problem is at risk, CBA is adopted as mechanical stabiliser in subgrade soil. According to Cadessa [5] the use of CBA as a mechanical stabiliser in subgrade soil resulted in an increase in California Bearing Ratio (CBR) value.

The physical properties of CBA which is semispherical and spherical shape with a rough surface of CBA basically increase particle interlocking and restrict movement between particles, therefore providing a desire mechanical stability of soil. Besides, due to the higher carbon content and porous vesicular texture of the particle in CBA exhibit lower sepecific gravity [6].

2. Materials and methodology

The materials used in this laboratory investigation consists of disposed coal bottom ash collected from coal thermal power plant in Lumut Perak and sample of subgrade soil obtained from PENS Holdings, Kangar Perlis. Laboratory test were carried out for samples of subgrade soil, coal bottom ash and mixture of both sample is according to BS 1377:1990.

2.1. Sample preparation

Sample preparation consists of physical test which are particle size distribution, Atterberg limit test and specific gravity test carried out to evaluate the mechanical properties of subgrade soil. Wet sieve is carried out to separate fine and coarse grain material in the soil. Dry sieve in accordance to the BS 1377-2:1990 clause 9.2 and 9.5. For particles passing 6 μ m sieve size, hydrometer sedimentation method is carried out according to clause 9.5 BS 1377-2:1990 [7]. Atterberg limit of subgrade soil is determined in accordance to BS 1377-2:1990 clause 4 to classify the plasticity of soil according to plasticity index obtained. Specific gravity is carried out to obtain the SG value.

2.2. Laboratory test

The Modified proctor compaction test under clause 6.4.2 of BS 1377:4:1990 to obtain the dry density and moisture content relationship. The test performed on air-dried coal bottom ash and soil samples. 95% of the maximum dry density was determined to obtain the moisture content to be applied in CBR test. Sample proposed are 0%, 20%, 30%, and 40% replaced into subgrade soil. By using automatic compaction machine and standard size mould, each of the four specimens was compacted in 5 layers, with each layer receiving 62 blows. After the moisture content is obtained at 95% MDD, California bearing ratio test is carried out.

By using the 1L mould size and 4.5 kg hand rammer, the compaction of CBR is done manually. The California bearing ratio test was carried out as per BS 1377:4:1990 clause 7 on samples of subgrade soil and mixtures of subgrade soil and coal bottom ash. For CBR testing, the samples were air dried and pre-treated for compaction as per clause 7.2 of BS 1377:4:1990 [7]. Since JKR requirements applied soaked CBR, the subgrade soil and mixtures containing 0%, 20%, 30%, and 40% by weight of coal bottom ash mixes were subjected to CBR tests in the soaked conditions. The CBR value is expected to obtain after the fifth day of test. The highest CBR value is the most optimum sample.

3. Results and discussion

3.1. Subgrade soil

3.1.1. Classification of soil. The subgrade soil sample had light reddish brown colour and had a rough surface texture with some gravel sized particles and cobbles. The particle size distribution of the soil is given in Fig. 1. The gradation test shows that the coefficient of uniformity (C_u) of soil obtained was 500 and coefficient of curvature (C_c) obtained is 16.2. The proportion of material obtained in the soil is shown in Fig. 1, where the highest with sand material with the total percentage retained is 50.64% followed by fine grained material, silts with 29.84% and clay with 11.86%. The least is gravel with 4.47%. The fine fraction had a liquid limit of 37.501% and a plastic limit of 20.323%. According to the British Soil Classification System, the soil sample can be classified as a poorly-graded sandy with some silt. Besides, the plasticity index obtained is 17.18% shows the high plasticity in the soil tested.

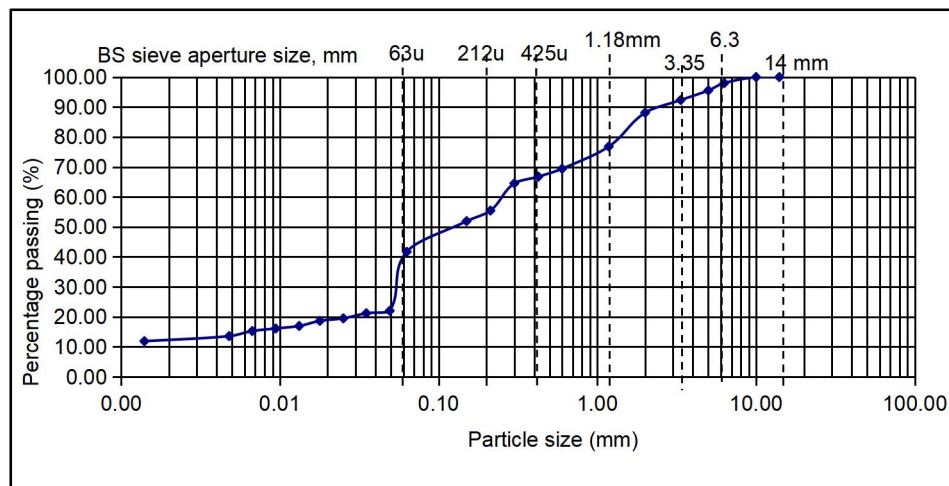


Figure 1. Gradation of subgrade soil.

3.1.2. Moisture-density relationship. A relatively low specific gravity value, G_s of 2.44, was obtained for the soil sample. A maximum dry density of 1.99 Mg/m^3 corresponding to an optimum moisture content of 15.34% was observed, as shown in Figure 2.

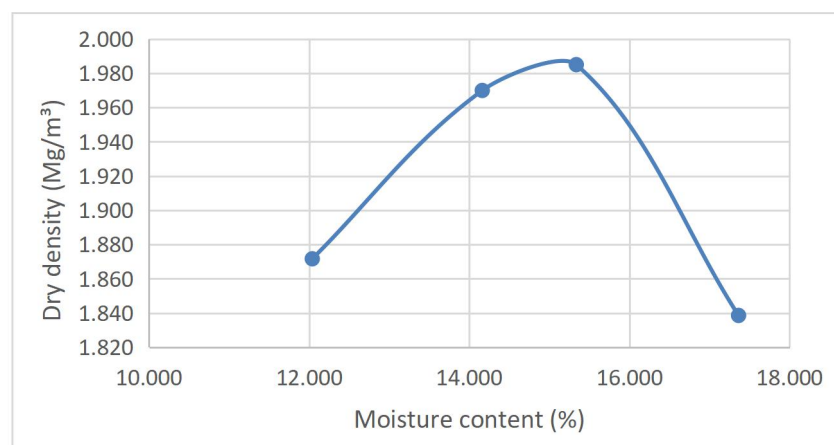


Figure 2. Dry density against the percentage of moisture content for subgrade soil.

3.1.3. California Bearing Ratio. The CBR value of un-soaked soil sample was obtained as 17.99% at 95% compacted dry density of 1.893 Mg/m^3 and at a corresponding moisture content of 12.45%. A relatively low swelling of 0.71% was observed at the end of the 4-day soaking procedure, which is desirable for pavement construction.

3.2. Mixture of subgrade soil with coal bottom ash

3.2.1. Moisture-density relationship comparison. Addition of bottom ash to the subgrade soil resulted in a mixture having lower MDD and OMC values as illustrated in Fig. 3. In corresponding to that, the value of OMC also decrease which is shown in Fig. 4, where the MDD of 30% CBA replacement obtained is 1.955 Mg/m^3 and OMC is 10.2% lower than the soil sample. Usually, coal bottom ashes exhibit lower maximum dry densities (MDD) compared to conventional granular aggregates which may be a result of the lower specific gravity of coal bottom ash [9, 10, 11]. In this research, the particle density of coal bottom ash was 2.26 Mg/m^3 , lower than that of the soil which is 2.44 Mg/m^3 such that the combined MDD of the CBA and subgrade soil mixture decreased with increasing CBA content.

The drop in MDD upon addition of CBA also caused drop in OMC where initially OMC in subgrade soil obtained is 15.34% to 10.2% with 70% soil and 30% CBA mix. This decline may be occurring due to the non-plastic nature of the coal bottom ash. Since coal bottom ash physically high porous surface and contains voids, the area surface available for water absorption also decrease. Thus, water absorption into these voids is less probable, leading to a decrease in moisture content. Rogbeck and Knutz [8] state that laboratory compaction curves for coal bottom ash generally exhibit lower optimum moisture content, demonstrating the insensitivity of coal to water.

3.2.2. CBR values with addition of CBA. The variation of the CBR value with coal bottom ash content in the soil is shown in Fig. 5. Addition of coal bottom ash generally increases the CBR value until reaching a maximum 30% coal bottom ash by weight, where un-soaked CBR values are the highest with 40.65% compare to soil which is 17.99%. This is due to the fact that addition of CBA leads to an increasingly particle interlocking which also leads to higher internal friction angle between particles. Internal friction angle is the ability to resist sliding along internal surface of soil by interlocking among the particles which then decrease the soil cohesiveness [9]. This caused the particles of soil and ash particles get more closely packed together automatically increase soil rigidity and shear resistance.

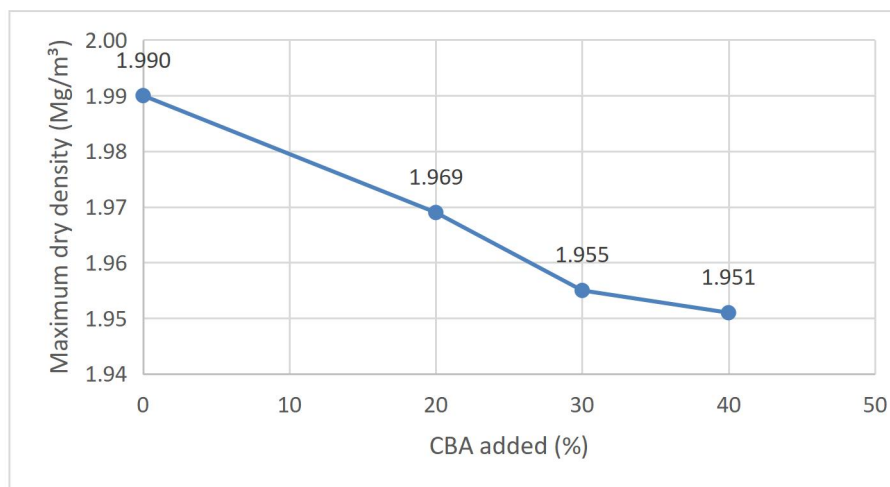


Figure 3. Moisture-density relationship with addition of CBA.

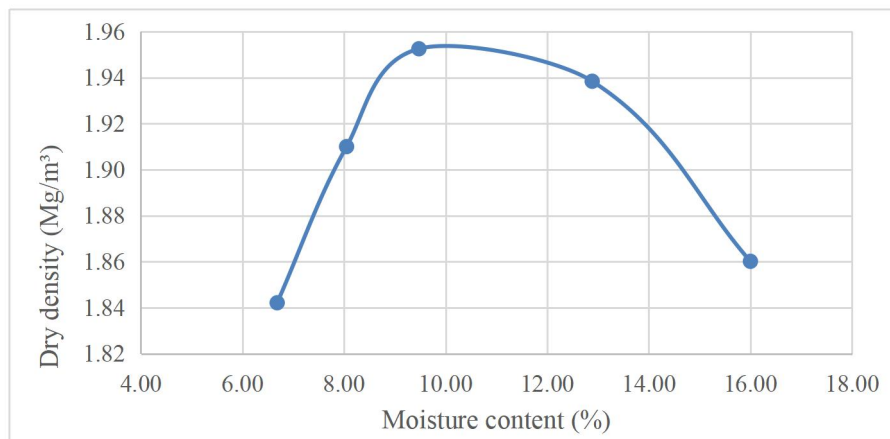


Figure 4. Moisture-density relationship for optimum proportion of 30BA:70SS.

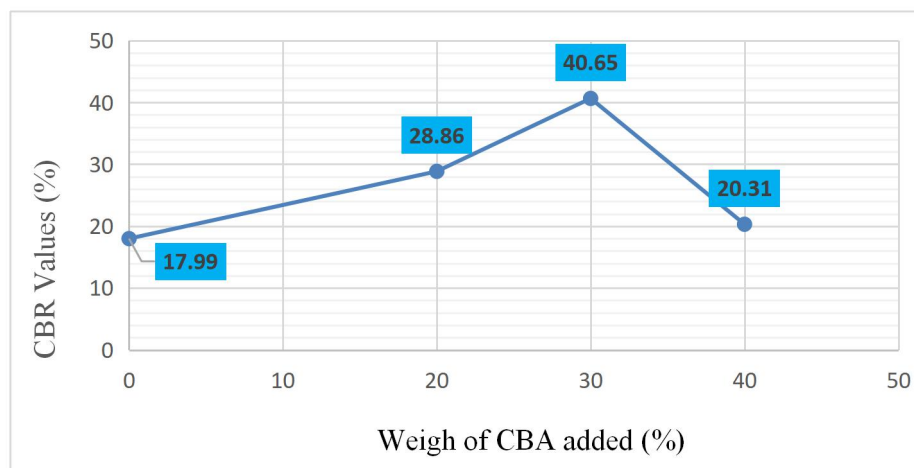


Figure 5. Graph of soaked CBR value with increasing CBA content.

However, a further increase in the CBA content causes the CBR value to decrease since the particle size of coal bottom ash starts to predominate the size distribution of the mix. Besides since the CBA is non plastic nature, with more CBA added has caused the reduction in cohesiveness of soil. Very low cohesive is also undesired as cohesiveness is significant for water absorption and bonding forces. However very high cohesiveness can cause leaching and low internal friction angle automatically drop the ability of particles to interlock. The drop in CBR at 40% percent replacement is also because of the rapid development of pore water. The water that was moved into the sample fails to be absorbed by CBA, this had caused the pore water to develop fast and the strong of valence bond between water molecular aggressively cut the soil interlocking and decrease the friction angle. Thus shear resistance of soil is decreased.

The effect of coal bottom ash content on the swelling potential is graphically illustrated in Fig. 6. Upon addition of coal bottom ash, a considerable decrease in swelling potential is observed, namely, a decrease from 0.71% (0% CBA) to 0.59% (30%CBA), which is in line with findings of Cardesa, Khodabacus and Rifa'i et al. [5,10,11].

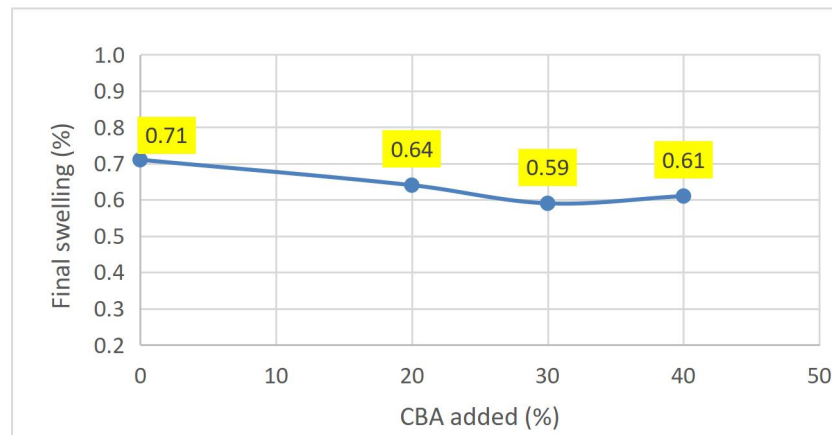


Figure 6. Final swelling against percentage of CBA added.

4. Conclusion

Addition of CBA to subgrade soil increases CBR value and decreases the swelling potential. In addition, as expected, a decrease in MDD upon addition of CBA to the soil was registered due to a lower specific gravity of the CBA. The investigation also demonstrates that CBA may effectively be used as a mechanical stabilizer for the subgrade soil on the pilot field stretch and that 30% by weight of CBA added to the subgrade soil yielded the highest soaked CBR values of 40.65%. The swelling potential decreased from 0.71% to 0.59% due to increase of CBA which is non plastic nature and not sensitive to water. Moreover, at a CBA content of 30%, the soil is of intermediate plasticity which is more desirable than the subgrade soil which is highly plastic. It is therefore recommended to use a mixture of CBA: subgrade soil of 30:70% for the fills below roads pavements, buildings, parking areas, subgrade construction, pipe bedding or airport development.

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