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Review: Application of coal bottom ash as aggregate replacement in highway embankment, acoustic absorbing wall and asphalt mixtures

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Abstract. Worldwide annual production of coal bottom ash waste was increased in the last decade and is being dumped on landfill over the years. Its improper disposal has become an environmental concern and resulted in a waste of recoverable resources. There is a pressing and on-going need to develop new recycling methods for coal bottom ash. The utilization of coal bottom ash in highway engineering is one of the options to reduce the environmental problems related to the disposal of bottom ash. The present review describe the physical and chemical properties of coal bottom ash waste and its current application as highway embankment material, as acoustic absorbing material and as aggregate replacement in asphalt mixtures. The purpose of this review is to stimulate and promote the effective recycling of coal bottom ash in highway engineering industry.

1. Introduction

Coal ash is a co-combustion products obtained from coal fired power plant station. Type, source, fineness of the parent fuel and the operating conditions of the power plant influenced the physical and chemical properties of bottom ash produced [1]. Fly ash is extracted from the boiler flue gases and bottom ash is the coarser part collected at bottom of the furnace [2].

Compared to fly ash, commercial usage of coal bottom ash is still left behind. However, it was reported that in developed country, about 50% of coal bottom ash has been utilized in civil engineering industry such as structural fill, road constructions, aggregate replacement for embankments and cement based composites [3].

Realizing the potential of coal bottom ash to be used in civil engineering especially in highway engineering, many researcher have studied ways to convert these waste into wealth. However there are limitations that need to be considered before consuming bottom ash waste in any construction. Its irregular structural characteristics, unburned carbon particles [4, 5, 6] and the possibility to leach heavy metals can bring harm to the environment and human being if not well treated [7, 8, 9].

2. Engineering properties

Generally, coal bottom ash has similarity with conventional aggregate used in construction industry. Physical and chemical properties influence coal bottom ash subsequent use and disposal. In environmental aspect, the treatment of coal bottom ash is subjected to regulations as a hazardous waste since it is not classified as general solid waste.

2.1 Physical properties

Physically, bottom ash particles is angular, porous, and sizes ranges from gravel to fine sand with very low percentages of silt-clay sized particles [10]. Usually bottom ash sizes ranged from sands to small sizes gravels [15]. By using soil classification system (USCS), coal bottom ash had been classified as well graded sand and falls into group A-1-a using AASHTO classification system [11].

2.2 Chemical properties

Generally, bottom ash is mainly composed of silica, alumina, iron, etc. The relative elemental abundance in coal was found to be in the order of Si>Al>Fe>Ca>Mg >K>Na>Sr>V>Zn>Mn>Cr>Cu>Pb>Ni>Co>As>Cd while the order of relative elemental concentration in bottom ash was found to be Si>Al>Fe>Ca>Mg>K>Na>Mn>Sr>V>Zn>Ni>Cr>Cu>Pb>Co>Cd>As [12]. Overall, bottom ash waste was safe to be used in industrial products especially in civil engineering industry. However, the presence of toxic elements such as Cr and Pb should be considered before recycling coal bottom ash waste.

3. Comprehensive application

3.1 Highway embankment

Research on the utilization of coal bottom ash in highway embankment has been presented in previous studies [13, 14, 15]. The suitability of bottom ash in highway embankment has been investigated. Material used in highway embankment should have good drainage properties, lower plasticity, and high in strength, stability and compacted density.

From previous study, findings that bottom ash has higher specific gravity compare to fly ash [13] due to its higher iron oxide content. Its helps bottom ash to transmit less dead load to the soil that supports the embankment.

Normally higher compaction applied, will leads to higher maximum density and lower the optimum water content [15]. The increasing of the dry density was contributed by the crushed particle of bottom ash during compaction [13]. However, the addition of fly ash to the bottom ash mixture leads to increase the well graded distribution. As a result, maximum dry density increased as fly and bottom ash particles were pack more closely [15]. However, the finding showed that compacted ash mixtures are potentially corrosive. Therefore, as precaution, it is recommended to use corrosion resistant materials if any pipes or structural members are embedded in ash fill [16].

Bottom ash particles have bigger voids compare to fly ash. The values of hydraulic conductivity decreasing gradually by increasing of coal ash content as the fines included in coal ash especially bottom ash has a predominant effect on the permeability [15]. In addition, high permeability of coal bottom ash and natural soils mixture is suitable for the drainage in backfill materials in embankments where a high amount of annual rainfall occurs [14].

In compressibility aspect, regardless of the ash sources, a general observed trend is the ash samples become more compressible than conventional sands with the increasing of bottom ash. Both surface texture and particle crushing in coal bottom ash had influenced the increasing of compressibility.

Besides, the ability of soils or any materials to resist loading without failing, is also important characteristic that should be considered in highway embankment construction [15]. Therefore shear strength of the soils or materials should be determined before proceed to construction works. Due to the angularity of bottom ash particle, the friction angle increased with the increasing of bottom ash content. This provides higher resistance to particle rearrangement for sustained shearing [13].

It has been reported that, shear strength of coal bottom from Tanjung Bin Power Plant, Malaysia has been decreased without the addition of fly ash as the bottom ash exhibits small cohesion characteristics [13]. The addition of bottom ash increases critical state friction angles gradually while peak friction angles do not change significantly with increasing bottom ash content. The critical state shear strength of ash mixtures is in a very similar range to that of typical sand.

3.2 Acoustic Absorbing Materials

Other potential use of coal bottom ash waste is as acoustic absorbing materials in highway pavements. Findings show that, finest particles of bottom ash produced material with good mechanical properties, while, larger particle produced excellent sound absorption coefficients [17].

Reverberation test and transmission loss index curve from previous study prove that bottom ash as absorbent materials can be classified in the same category with conventional road noise barriers concrete [18].

Larger particles size of bottom ash decreased the surface area which then requires less water to lubricate the particles. On the other hands, the void ratio and the density of the mortar tends to increase with the increasing of bottom ash particles size. Increasing of the open void ratio had cause the decreasing of compressive strength of mortars [17]. It has been reported in latest study, that density and compressive strength of acoustic absorbing material made from 80% of bottom ash are similar to those found in barriers made of conventional or recycle materials [18].

In addition, the replacement of fine and coarse aggregates with co-combustion products (fly ash and bottom ash) have a remarkable influence on fire resistance without affecting the mechanical properties of the acoustic absorbing material produced [19].

3.3 Asphalt Mixture

3.3.1 Filler in bituminous mixture Optimum binder content increased with the present of bottom ash and/or hydrated lime due to high specific surface of both and the high porosity of the ashes. High porosity of the ashes leads to higher absorption values [20, 21]. Densities of mixes with bottom ash were higher than control mixes due to the lower specific density of lime and ashes. The highest densities are reached for a combination of around 70% bottom ash and 30% hydrated lime. Higher density values indicate better performance and longer lifespan of the pavement. This mixture is recommended for road surfaces and intermediate layers with light traffic and small infrastructure [21]. However, previous research has been reported that the replacement of bottom ash in asphalt mixtures produce a lower dynamic modulus and higher rutting potential compared to control mixture [20].

3.3.2 Aggregate replacement Bottom ash has been used as base course in cold mix asphalt with low traffic volume. Utilizing coal waste and its ash was proven in improving the mechanical properties in cold recycled asphalt mixture which Marshall stability, tensile strength and resilient modulus were increased due to its higher pozzolanic content [22]. Previous studies also show that, bottom ash more suitable to be used in the base course and shoulder area due to the lower durability and lower abrasion resistance [23]. Besides, it also might be used in secondary roads with low traffic volumes and in parking lots and driveways which has low effect on short term tensile strength [24].

Recent studies indicate that, when bottom ash was used as partial replacement of fine aggregate, the bituminous performance was equal to conventional mixes [25]. However, the accepted percentage of bottom ash to be used as aggregate replacement must be less than 30% as mixes with 50% or more were found to have low stabilities [26]. The asphalt content increased with increasing of percentage of bottom ash [27]. However, even though bottom ash were coated with asphalt, the present of pyrites tend to weather during life service and causing deep red stains in pavement surface [28].

4. Conclusion

The production of coal bottom ash is expected to be increased year by year. The potential to utilized coal bottom ash in engineering field seem to be bright. Based on the review of previous studies, it has been reported that the utilization of bottom ash are still in the early stage of commercialization. Therefore further studies are needed to turn bottom ash waste into commercial reality. If proper design and construction procedure were followed, it appears that coal bottom ash is a suitable waste to be recycled into wealth especially in highway engineering field. However, it must first meet the environmental requirements set by state regulatory agencies.

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