The Potential of High Flow Concrete Mixtures Utilizing Recycled Coal Bottom Ash as Underground Cable Trench Backfill Material

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Abstract. In this study, the potential recycling Coal Bottom Ash (CBA) through replacing sand in flowable fill for cable trench backfill is determined. The new material is targeted to replace the soil backfill of narrow trenches to mitigate problems related to compacting soil backfill.. Targets were set for the workability, flowability, compressive strength and thermal resistivity, which corresponds to suitable properties for cable trench backfill. Three (3) concrete mixes were made as preliminary trial mixes for preliminary testing. Mix No.1 is a control mix made with cement and sand. Mix No.2 was prepared through substituting 50% of the natural sand content of Mix No.1 with CBA. In Mix No.3, CBA is fully used as the aggregate. In the Slump test, only that Mix No.3 fulfils the workability and flowability targets. All three mixes exceeded the limits for compressive strength. It is found that only Mix No.1 and Mix No.2 fulfils the requirement for thermal resistivity. In conclusion, recycled CBA can potentially be utilized in flowable fill for underground cable trench backfill, however more studies must be conducted to further improve the mix design to fulfil the requirements.

1 Introduction

Among the most commonly used fuel in thermal power plants is coal, which is a sedimentary deposit found in abundance and readily combustible, generating large amounts of heat. A typical coal power plant burns tons of coal as fuel daily, which in turn produces large amounts of Coal Combustion Products (CCP), generally consisting of ash and slag. Around 750 million tonnes of coal ash is estimated to be produced by the coal industry globally[1]. Majority of the coal ash produced are in the form of Coal Fly Ash (CFA) (70-80%), and the remainder being Coal Bottom Ash (10-20%) [2].

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Coal Bottom Ash (CBA) are coarse and glassy particles that fall to the bottom of the furnace, and have been used in limited application such as manufacturing of blocks and filler for road construction foundation [3]. In past studies, CBA has been seen as suitable substitute for fine aggregates, due to it having similar fineness modulus (FM) to river sand, which is approximately 1.6-2.2 [4]. A study conducted on two samples of CBA produced from the combustion of Russian bituminous coal and Indonesian subbituminous coal has also shown that the CBA test satisfies the requirements for aggregates in the Spanish code for structure concrete [5].

Although there are some applications for the recycling of CBA, the overall utilization of this material is still low. For example, 60% of the CBA generated in Korea is landfilled, and only 40% is recycled [6]. In Coal Power Plants, unutilized CBA are generally disposed through landfilling in ash ponds, which are ring embankments engineered specifically to prevent any release of leachate to groundwater and to the surrounding area.

However, the ever increasing amounts of unutilized CBA stockpiled at these coal ash ponds may be a potential human health hazard and environmental issue, due to airborne dispersion of fine particulate, or the release of heavy metals from coal ash. A study in the United States has shown that participants which are living near to a coal power plant having coal ash storage facilities are more likely to report frequent coughing (36.8% vs 9.1%), frequent short of breath (33.6% vs 9.1%), hoarseness (15.9% vs 1.2%) and respiratory infections (16.8% vs 2.42%) compared to a non-exposed group [7]. In tests carried out on Mozambican coal and coal ash samples, it was found that from 6 ash samples, high concentrations of As was leached from one sample, while two other leachate samples showed higher concentrations of Cr^{3+} and Mn [8]. However, studies have also shown that the leaching of Ar and Se from coal ash is dependent on the on-site geochemical conditions as well [9].

Thus, the recycling of CBA would be beneficial as it reduces the amount of coal ash stockpiles in the coal power plants, which in turn mitigates the risks to the surrounding population as well as the environment. The recycling of these unwanted material can also contribute towards sustainable development and reduction of the overall carbon footprint of the construction industry. CBA can be used replace aggregates such as natural sand and reduce environmental devastation associated with mining of these aggregates. Sustainable management of these material fulfils the target of the United Nations Sustainable Development Goals (SDGs) No. 12, which is to "ensure sustainable consumption and production patterns" [10].

One potential application identified for the recycling of CBA is to produce high flow concrete or flowable fill for backfilling cable trenches. Cable trenches are generally made to lay underground cables by utilities, usually in urban areas. This is because in such areas, usage of overhead cables would be difficult due to requirements of securing right-of-way for support structures such as poles and towers. Burying cables deep underground also helps in ensuring the safety of the general public. These trenches can be up to several meters deep, with varying widths depending on the type and number of cables to be laid.

Usually, after the trenches are excavated and cables laid at the bottom of the trench, the trench is filled with river sand backfill and compacted to ensure that the surface of the trench does not subside. However, some trenches may be too narrow to be compacted properly using machinery. Thus, there is a need for a new backfill material which can replace soil backfill that does not need to be compacted and easily applied at site.

2 Materials Used

The CBA used in this study is collected from the coal ash pond of the Sultan Salahuddin Abdul Aziz Coal Power Plant (also known as Kapar Energy Ventures, or KEV), which is located in Kapar, Malaysia. The CBA is excavated from the existing stockpile which has been landfilled into the coal ash pond, and then stored into 1 ton bulk bags for transportation. Figure 1 below shows the condition of the CBA during collection and the loading process.

(a)	(b)

Fig. 1. Collection of CBA from Coal Ash Pond. (a) Condition of CBA during collection (b) Loading CBA into bulk bags for transportation.

Sieve analysis was conducted on the CBA collected to determine its grading. The test was conducted based on BS 812: Section 103.1:1985. The results of the sieve analysis is shown in the Figure 2. From the sieve analysis conducted, it is shown that the CBA collected has particles which mostly falls between the limits specified for sand in BS 882:1992 Table 4. However, the amount of particles finer than 0.15 mm exceeds the limits slightly, which indicates that there is a higher portion of very fine material. Thus, it is shown that the CBA collected may be used as sand replacement for concrete.

In this study, Sika ViscoCrete-2192 is used as a Superplasticizer, which is a modified polycarboxylate which is added in a flowable fill mixture to increase the workability and flowability of the concrete mix. The dosage used for this study is 500 ml per 100kg cement, which is the lowest recommended dosage set by the manufacturer data sheet.

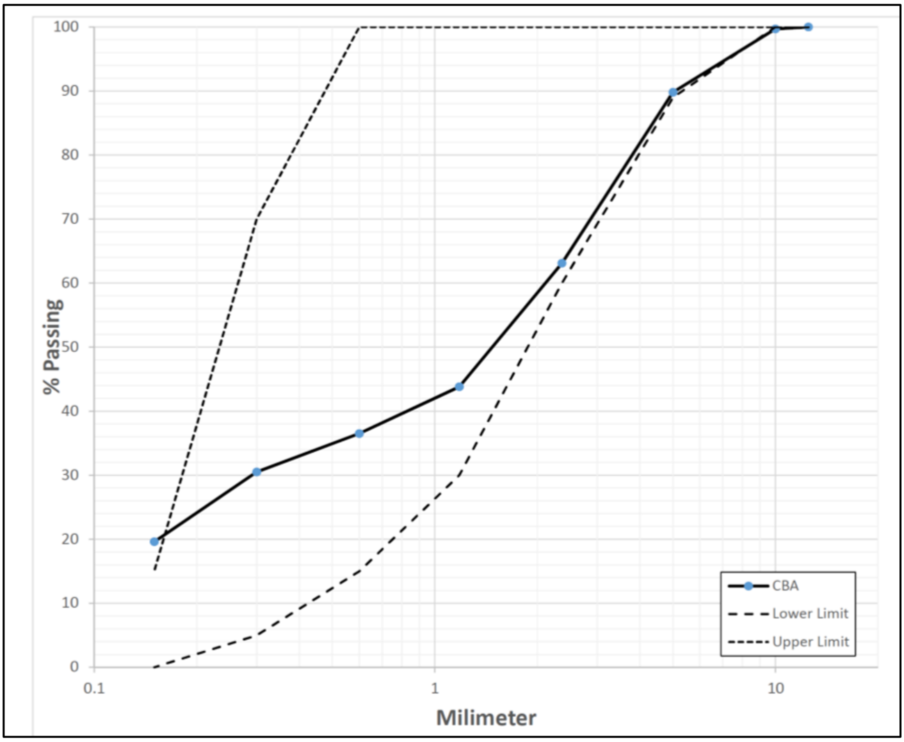

Fig. 2. Results of Sieve Analysis on CBA sample from KEV

3 Target Requirements for Cable Trench Backfill Material

3.1. Workability

The new cable trench backfill material must be able to self-compact, which is the ability to fill gaps and crevices without compaction by machinery or vibration. This property is important as the formation of voids within the backfill may cause the formation of potholes and surface subsidence along the trench, due to these voids collapsing under the load of soil or traffic above the trench. To measure the potential of self-compacting, the trial mixes will tested for their workability and flowability.

To determine the workability, a slump test is usually conducted on fresh concrete samples. The slump test is conducted with reference to BS EN 12350-2. It involves determining the amount of depression ('slump') of the concrete sample which has been moulded in an Abrams slump cone. In this test, higher slump values indicate higher workability. Figure 3(a) shows the Slump Cone used and the Tamping Rod for compaction. According to BS 8500, trench fills must have consistence class of S4 which corresponds to a slump value not less than 150 mm and not more than 230 mm for composite sampling [11].

3.2. Flowability

Flowability measurements are taken using a flow table apparatus which is used in conjunction with the slump test cone from the workability test. The flow table apparatus is shown in Figure 3(b) below. The spread of the concrete after the removal of the slump cone is record in two directions, d1 (maximum spread) and d2, which are 90 degrees perpendicular to each other. To calculate the slump flow (SF), Equation 1 below is used, which is referred from BS EN 12350-8.

$$SF = (d1 + d2) / 2 \quad (1)$$

The targeted SF is SF of 760 – 850 mm, which corresponds to an SF class of SF3 for mixes produced using small maximum size of aggregates and is suitable for vertical applications in very congested structures, structures with complex shapes or for filling under formwork [12] . This would ensure that the mix is capable to fill the cable trench evenly and no gaps will be present under or in between the cables buried.

(a) (b)

Fig. 3. Apparatus for Workability and Flowability (a) Slump Cone and Tamping Rod (b) Flow Table

3.3. Low compressive strength

Compressive strength tests were conducted according to BS EN 12390-1:2000. The compressive strength of a mix is determined through a compressive test using a hydraulic cylinder apparatus on a 150 mm cube sample, which has been cured for 28 days in a water bath. The final compressive strength result recorded before the sample yields is taken as the compressive strength of the mix.

Cable trenches may need to be excavated in the future to access the buried cables for maintenance. Thus, the new cable trench backfill material must easily excavatable, using standard machinery such as a backhoe or excavator. To achieve this, the flowable fill must have an final compressive strength of 1.0-1.4 MPa to allow for excavation using mechanical equipment [13].

3.4. Thermal Resistivity

Electricity cables generate heat during operation, thus it is important that the new cable trench backfill material is able to dissipate this heat to ensure safe and efficient operation.

In this study, the thermal resistivity is measured to determine its suitability for usage. To conduct this test, the measurement of the thermal resistivity is taken using a thermal properties analyzer. The backfill material is casted into a container, and during casting, the thermal properties analyzer probe is penetrated into the sample to create a hole for measurement.

The thermal resistivity is measured after allowing the material to harden for 7 days. For cable trenches, the usual reference material used for backfilling is sand, which has a thermal resistivity of 1.2 ^{o}C.m/W. Thus, the new cable trench backfill material must have a thermal resistivity which is equal or less than sand.

4 Preliminary Trial Testing Results and Discussions

Preliminary trial testing is conducted to determine suitable methods for handling, behaviour during mixing and to gauge the suitability of tests outlined in Section 3. Three (3) preliminary trial mixes were prepared and tested to determine the suitability of the methods outlined above. Mix No.1 is prepared only with cement, natural coarse sand and water, and is used to be as a benchmark. Mix No.2 is a prepared by substituting the half of sand component of Mix No.1 with CBA, while Mix. No. 3 is a full CBA substitution mix. The mix ratio (by weight) for all trial mixes are presented in the Table 1 while the results of the slump, flowability and compressive strength testing are summarized in Table 2 below:

Table 1. Mix Ratio for Trial Mixes

Mix No.	Aggregate Used	Material Ratio			Water-Cement Ratio
		Cement	CBA	Sand	
1	Sand Only	1	0	5	0.4
2	50% Sand, 50% CBA	1	2.5	2.5	0.4
3	CBA Only	1	5	0	0.4

Table 2. Results of Slump, Flowability, Compressive Strength and Thermal Resistivity Tests

Mix No.	Slump Test (mm)	Flowability Test			Comp. Strength (MPa)	Thermal Resistivity (^{o}C.m/W)
		d1 (mm)	d2 (mm)	SF (mm)		
1	0	0	0	0	9.87	0.516
2	25	0	0	0	4.60	0.982
3	225	1,290	1,170	1,230	5.60	1.680

From the tests conducted, changes to the concrete property were observed due to substituting sand with CBA. The substitution of natural sand with CBA improves the workability and flowability of a concrete mix at similar water-cement ratios. This is observed by comparing the change in slump and flowability, where increase in workability and flowability is seen with the increase in CBA substitution, although the mix has similar water-cement ratio of 0.4. The high workability and flowability of Mix No.3 also fulfils the targeted slump and flowability values outlined in Section 3.

A drastic reduction in the compressive strength is seen with 50% CBA substitution, which can be attributed to the weakness in the CBA particles, which are porous and brittle. Slight increase in the compressive strength is observed at full CBA substitution, which is most likely attributed to the higher volumes of CBA used compared to sand, as CBA is less dense compared to sand. All three mixes did not fulfil the targeted compressive strength requirements outlined in Section 3.

Increase in CBA substitution also results in higher thermal resistivity values. The thermal resistivity increases from 0.516 ºC.m/W in Mix No.1, followed by 0.982 ºC.m/W in Mix No. 2 and finally 1.680 ºC.m/W in Mix No.3. It is found that Mix No.3 has exceed the targeted requirement for thermal resistivity. This increase is seen to be related to the porous particles of CBA, which trap air consequently increasing the resistivity.

In the future, a more structured testing regime will be conducted to properly investigate the changes in the properties of the backfill material. More studies on the mix design will be conducted to determine the best mix ratio to achieve lower compressive strength values and high flowability, while reducing the thermal resistivity. The Superplasticizers dosage can be optimized to keep the water-cement ratio low which would minimize the potential of drying shrinkage associated with high water contents. The California Bearing Ratio (CBR) test can also be conducted on hardened samples to determine the backfill material suitability against local guidelines for backfill material.

5 Conclusion and Future Studies

It is shown that CBA has the potential to be competent natural sand replacements in high flow concrete for cable trench backfill material. Preliminary Trial Testing has produced a high workability and highly flowable concrete was made using CBA, which performs better than equivalent mixes using natural sand. By using recycled CBA and reducing the usage of natural sand, improvements to the sustainability and carbon footprint of the backfill material can be realized as it reduces environmental devastation. Recycling CBA also helps to alleviate the potential hazards associated with coal ash disposal at Coal Power Plants by reducing the ash stockpile.

6 References

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