

# Effect of high-volume coal waste on strength properties of concrete

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**Abstract.** The rapid growth in the construction industry has increase in the consumption of raw materials whereby it depletes the natural resources. Therefore, the need of abundant and cheap materials is increased. Also, coal waste is abundantly available from coal generating power plan. The aim of this research is to investigate the performance of concrete incorporating high volume coal waste as cement and aggregates replacement. The specimens are prepared by using 30% coal fly ash as cement replacement and fully replacement of aggregates with coal bottom ash. The specimens are cast using 100 mm x 100 mm x 100 mm cubes. There are several test conducted in this study for example, the test for characteristic of the materials, fresh and hardened properties of concrete. It was found that the workability of concrete decreases with the inclusion of coal waste. Overall, it is found out that the coal waste can be used as aggregates replacement in concrete since it has a comparable strength with a conventional concrete.

## 1. Introduction

In year 2020, the population in Malaysia will reached approximately 32 million which is 1.02% increment from year 2018 [1]. Construction industry is a major sector as an important part in development of economic in Malaysia. Malaysia is one of the developing countries where the constructions of many infrastructures are still ongoing and consequently, require high demand of concrete that will affect the use of natural aggregates resources [2]. Concrete has become predominant building material in the construction industry due to its excellent mechanical and physical properties when properly designed and manufactured. More than 10 billion tonnes of concrete are produced annually. As it has been estimated that the rate of world's population will increase, thus, this will increase the demand for housing as well as the concrete materials which are estimated to be 18 billion tonnes by 2050 [3]. Previously, researchers have focused on finding materials that have similar properties as cement and aggregates but more sustainable and affordable. Since aggregates is the major building material, finding an affordable cost substitution material is a necessity to reduce the overall cost and depletion of natural resources. The need towards sustainability and sustainable environment has made the use of waste material in construction popular. Within these few years, natural and industrial



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wastes have been used as construction materials namely, ceramic tile waste, pumice aggregates, oil palm kernel shell (OPKS), waste glass and laterite aggregates [4-8].

Besides, waste management is a very difficult problem and the vital tasks in near future will be to increase the practical of 3R (recycle, reuse and reduce), economic utilisation and lowering storage. In Malaysia, nearly 40% of the electricity production is shared by coal. In 2030, 49 percent of electricity production will be shared by coal power generation [9]. Combustion of immense volumes of coal in the power plants results in large scale of toxic by-product production which include coal bottom ash. Coal power plant in Malaysia had accumulated huge volumes of coal bottom ash for decades. Tanjung Bin is one of the biggest coal-fired power plants in Malaysia to generate electricity [10]. The by product from burning of the coal ash produce 42,000 metric tonnes of fly ash and 8,000 metric tonnes of bottom ash every month. The disposal method of coal waste not only will contaminate underground water and affect living organisms, it also will cause highly hazardous and toxic to human health. In addition, excessive mining of river sand which act as the prime construction material will result in unbalancing ecological system and natural resources are depleting gradually [11]. The coal ash content depends upon the non-combustible matter present in coal. Coal bottom ash is composed mainly of silica, alumina and iron with small amounts of calcium, magnesium sulphate, etc. The particle shape, surface texture and particle size distribution are similar to that of river sand and granite. Finding new way to recycle this waste in construction of infrastructures not only can be useful to preserve natural resources and environment, it can also improve the quality of concrete and reduce the cost of construction. To evaluate the true potential of coal wastes for new applications, as aggregates replacement, a comprehensive and detailed study of the fundamental properties of the material is highly needed.

## 2. Methodology

### 2.1 Materials

The binder used was Portland cement type I as stated in the ASTM C150-15 [12], 'Standard Specification for Portland Cement', which was purchased directly from the manufacturer. Then 30% of coal fly ash was used as cement replacement in the concrete mix design based on optimum strength from previous researches [13, 14]. Coal bottom ash was used as fully fine and coarse aggregates replacement. In the preparation process for all specimens, the aggregates were used in the saturated surface dried condition. The coal waste was obtained from coal power plant in south region of Malaysia. The size of coal waste used as coarse aggregates is 4.75 mm until 10 mm while the size of coal waste used as fine aggregates is less than 4.75 mm. The chemical composition of cement and coal fly ash used are shown in table 1. Meanwhile, the coarse and fine aggregates used are shown in Figure 1.

**Table 1.** Chemical composition of binder

Chemical composition (%)	OPC	Fly Ash
SiO <sub>2</sub>	16.40	46.7
Al <sub>2</sub> O <sub>3</sub>	4.24	35.9
Fe <sub>2</sub> O <sub>3</sub>	3.53	5.0
CaO	68.30	3.9
K <sub>2</sub> O	0.22	0.5
MgO	2.39	0.8
CO <sub>2</sub>	0.10	-
SO <sub>3</sub>	4.39	-
LOI	2.40	0.11



**Figure 1.** Coal bottom ash used in the research.

**2.2 Mix Design**

All concrete specimens were prepared with 0.5 water cement ratio, whereby the aggregates were prepared in saturated surface dry condition. The mixing was carried out in a room temperature of approximately 28°C. The mix proportions of concrete mixes are given in Table 2. The test specimens were prepared in 100 x 100 x 100 mm cubes. The specimens were compacted in three-layer with tamping rod. Additional vibration of about 10s was applied using vibrating table. The specimens were removed from mould after 24 hours and placed in water for 7, 14 and 28 days.

**Table 2.** Mix proportion of concrete mixes

Mixes	Binder (kg/m <sup>3</sup> )		Coarse Aggregates (kg/m <sup>3</sup> )		Fine Aggregates (kg/m <sup>3</sup> )	
	Cement	CFA	Granite	CBA	Sand	CBA
Control	440	-	780	-	881	-
Coal Concrete	308	132	-	769	-	881

\*CBA – Coal Bottom Ash, CFA – Coal Fly Ash

**2.3 Test Methods**

The characterization of coal waste was determined using grading test, bulk density test, crushing index test and water absorption test. The fresh and hardened state properties of concrete with replacement of coal waste in concrete were determined. During the fresh state of concrete, the concrete will be tested for workability by conducting slump test while in the hardened state of concrete, the concrete will be tested for the compressive strength of concrete at 7, 14 and 28 days.

**3. Results and Discussion**

**3.1 Physical Properties of CBA**

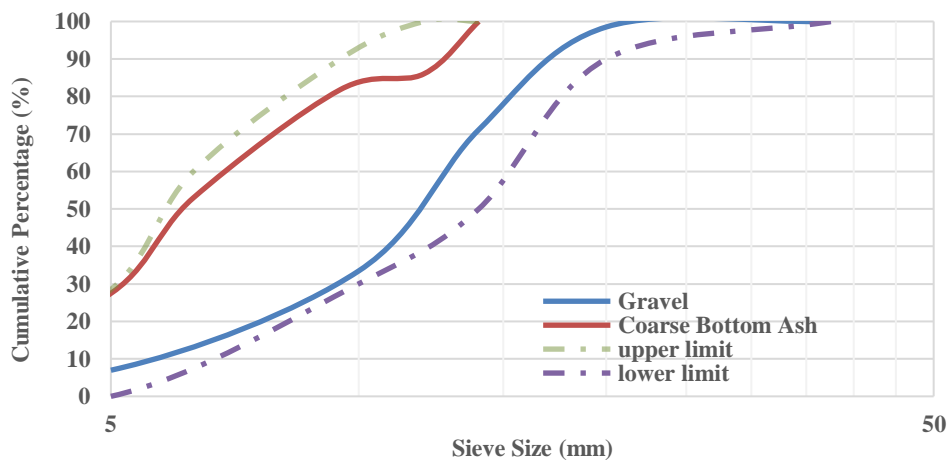
Table 3 shows the physical properties of aggregates used. Since the density of coal bottom ash is less than sand and granite, adding large amount of coal bottom ash reduced the density of concrete. Previous findings reported that the bulk density of coal bottom ash was in the range of 700 to 1400 kg/m<sup>3</sup> and it depends on the size of aggregates [15]. The specific gravity for sand, granite and coal bottom ash are 2.62, 2.7 and 1.22, respectively. Similar findings reported that the range of specific gravity of coal bottom ash were between 1.39 and 2.8 [15]. The water absorption at 24 hours for sand, granite and coal bottom ash are 3.4%, 1.8% and 26.5%, respectively. Coal bottom ash show a higher water absorption due to the porous surface. Therefore, the coal bottom ash need to be in saturated surface dry (SSD) condition before it can be used in the preparation of concrete.

**Table 3.** Physical properties of aggregates

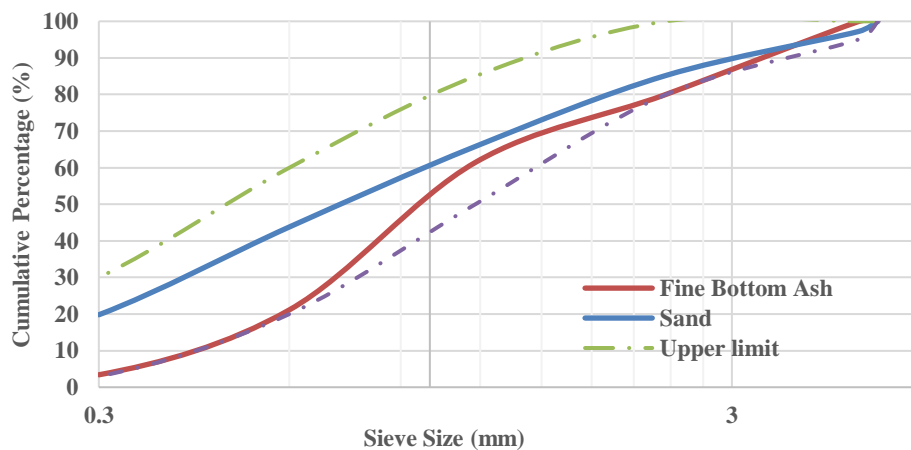
Properties	Sand	Fine CBA	Granite	Coarse CBA
Oven dry basis, bulk density (kg/m <sup>3</sup> )	1624	910	1580	770
Specific gravity	2.62	1.75	2.7	1.22
Water absorption at 24 hours (%)	3.4	34.6	1.8	20

**3.2 Grading of CBA**

In order to use coal bottom ash as aggregates in concrete, the grade of the coal bottom ash has to be ensured pass the sieve analysis test and be compared with sand and granite. The sieve analysis of granite and coarse bottom ash is shown in Figure 2 while sieve analysis of fine coal bottom ash and sand used is shown in Figure 3. The upper and lower limits were derived according to ASTM C33-13 [16]. From the sieve analysis, it shows that the particles distribution of coal bottom ash used in this research did follow the overall limit by ASTM C33-13. Therefore, the coal bottom ash can be used as aggregates to replace sand and granite. This is because aggregates that falls within the ASTM C33-13 grading limits usually produce robust and stable concrete. A well graded aggregates, usually reduces the demand for water and thereby, improving the packing density, robustness and workability of the concrete [17].



**Figure 2.** Sieve analysis of coarse and fine aggregates.



**Figure 3.** Sieve analysis of coarse and fine aggregates.

**3.3 Workability**

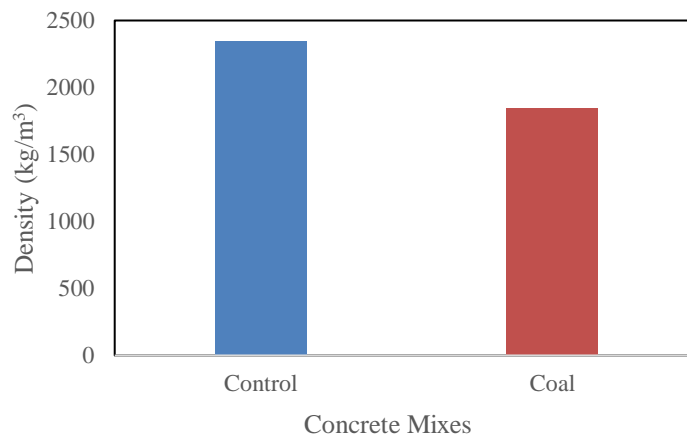
Table 4 show the slump that obtained from different mix proportions. From the results obtained, coal waste concrete mix has 90 mm slump whereas control concrete mix has 140 mm slump. The slump result of fully bottom ash replacement concrete mix is much lower than the slump result of control concrete mix. This is due to high water absorption properties of bottom ash, so the workability of fully bottom ash replacement concrete mix decrease.

**Table 4.** Workability of concrete mixes

Concrete Mixes	Slump Value (mm)
Control	140
Coal	90

**3.4 Hardened Density**

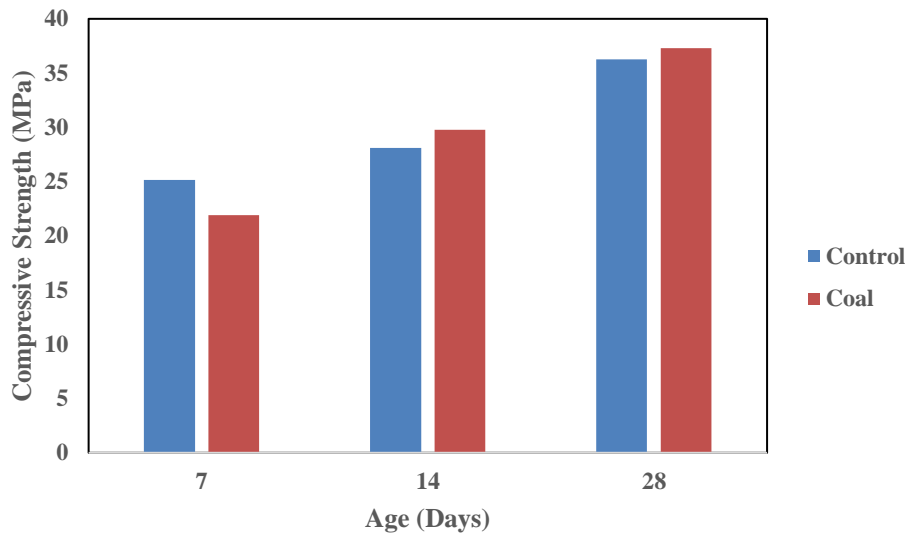
Figure 4 shows the hardened density of different mix proportions at 28 days. As shown in the figure, the density for 100% fully bottom ash concrete and control mix concrete are 1850 kg/m<sup>3</sup> and 2350 kg/m<sup>3</sup>, respectively. The density of 100% fully bottom ash concrete is lower than the control concrete which consists of granite and sand as aggregates. This is due to the low density of bottom ash aggregates compare to granite and sand aggregates.



**Figure 4.** Effect of coal waste on hardened density of concrete at 28 days curing

**3.5 Compressive Strength Test**

Figure 5 shows the compressive strength of 100 mm x 100 mm x 100 mm cubes at 7, 14 and 28 days after casting. As shown in the figure, 100% fully bottom ash replacement concrete has 37.28 MPa compressive strength while conventional mix design concrete which casts using granite and sand has 36.28 MPa compressive strength. Therefore, 100% full bottom ash replacement concrete has comparable compressive strength with the conventional mix design concrete which casts using granite and sand. This is because 100% fully bottom ash replacement concrete consists of higher amount of filler compare to conventional mix design concrete that will fill the spaces between the porous and thus increase the bonding strength between aggregates and cement. It also causes 100% fully bottom ash replacement concrete is denser than conventional mix design concrete.



**Figure 5.** Effect of coal waste on compressive strength of concrete

#### 4. Conclusion

In conclusion, the coal waste shows an acceptable characteristic as aggregates and can be used in concrete production. The density of 100% fully bottom ash concrete is 19 % lower than the control concrete which consists of granite and sand as aggregates. 100% fully coal bottom ash replacement concrete has comparable compressive strength with the conventional mix design concrete which casts using granite and sand.

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