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On the Performance Analysis and Environmental Impact of Concrete with Coal Fly Ash and Bottom Ash

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Abstract

Coal is a commonly used fuel by coal power plants that produce coal fly ash and coal bottom ash (coal FABA) as byproducts. The latest regulation in Indonesia changes coal FABA classification to non-toxic waste, which opens up its utilization possibility. This paper analyses the coal FABA potential from Suralaya Coal Power Plant as concrete material and its environmental impact. To determine coal FABA potential, the methods used in this paper are slump test, compressive strength test, flexural strength test, and carbon footprint calculation. This paper shows that concrete mixture with coal FABA content has a lower slump value, lower compressive strength, and generally lower flexural strength. Furthermore, the carbon footprint calculation result shows that concrete mixture with coal FABA content has lower CO_2 emissions than conventional concrete. Finally, the result shows that concrete with coal FABA could be used as non-structural concrete.

Keywords: carbon footprint, coal bottom ash, coal fly ash, concrete

1. Introduction

Coal is a commonly used fuel by coal power plants. To produce energy, power plants use coal as fuel and produce coal fly ash and coal bottom ash (coal FABA) as byproducts. However, residual ash from the coal burning process could pollute the environment due to its heavy metal content that could dissolve the surrounding environment [1]. One of Indonesia's largest coal power plants is Suralaya Coal Power Plant. Suralaya coal power plant started operation in 1980 and currently produces electricity for Java Island and Bali Island [2]. Suralaya coal power plant consists of 7 production units with a total capacity of 3400 MW. In generating electricity, the Suralaya Coal Power Plant produces a high amount of coal FABA. Therefore, it is necessary to utilize coal fly ash and coal bottom to reduce their environmental impact.

There are numerous pieces of research on coal FABA viability as concrete material. Several pieces of research results show that concrete strength increments from partial cement substitution with coal fly ash [3-4] and partial sand substitution with coal bottom ash [5-6]. Research also shows that the concrete strength increment is affected by the amount of coal FABA in the concrete mixture [7]. However, some research also indicates that coal FABA could reduce concrete strength compared to conventional concrete [8-11]. These results are caused by the different coal fly ash sources used in the research. Despite being classified as fly ash type F and type C, the chemical composition of fly ash from various sources greatly varies, which means the classification alone could not represent the fly ash performance in a concrete mixture [12]. Moreover, several pieces of research also show that coal FABA in concrete increases the concrete drying time and reduces workability [13-18]. Therefore, further research on the viability of coal FABA from the Suralaya Coal Power Plant as concrete material is necessary.

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In Indonesia, the utilization of coal FABA was hindered by their classification as toxic waste in national regulation. In Peraturan Pemerintah Nomor 101 Tahun 2014 [19], coal FABA is classified as “Limbah B3 dari Sumber Spesifik Khusus” (Toxic Waste from Special Specific Source). This classification obliges those utilizing coal FABA to have a toxic waste utilization permit. However, the latest regulation changes the classification of coal FABA into non-toxic waste. In Peraturan Pemerintah Nomor 22 Tahun 2021 [20], coal FABA are classified as “Limbah Non-B3 Terdaftar” (Registered Non-Toxic Waste). This classification change opens up the possibility of coal FABA utilization in Indonesia. However, it is still necessary to properly analyze the possible environmental damage of coal FABA utilization as concrete material.

This paper aims to analyze the potential of coal FABA from the Suralaya Coal Power Plant as concrete material and its environmental impact. The potential of coal FABA as the concrete material analysis was done by analyzing slump value, compressive strength, and flexural strength difference between conventional concrete and concrete with coal FABA content. The environmental impact analysis of coal FABA as concrete material was done by calculating the carbon footprint to determine the CO_2 emission difference between conventional concrete and concrete with coal FABA content.

2. Materials and Methods

Materials used in this research were water, Dynamix Brand type I Portland cement, sand as fine aggregate, crushed stone as coarse aggregate, and coal FABA from Suralaya Coal Power Plant. The water, cement, fine aggregate, and coarse aggregate used for each concrete type tested in this research were obtained from the same source to reduce the differences caused by material quality factors. The coal FABA obtained from Suralaya power plant had a chemical composition presented in Table 1.

Table 1 Chemical composition of Suralaya power plant coal FABA

Chemical composition	Coal fly ash	Coal bottom ash
SiO_2	46.93%	52.35%
Al_2O_3	24.47%	30.20%
Fe_2O_3	4.33%	0.06%
CaO	10.74%	0.34%
MgO	2.62%	0.08%
SO_3	3.26%	2.50%
Na_2O	0.32%	0.06%
K_2O	0.12%	0.02%
H_2O	0.14%	0.18%
Loss of ignition (LOI)	1.02%	2.64%
Source: Suralaya coal power plant, 25 May 2021 coal fly ash and coal bottom ash TCLP test result		

From a previous study done by [21] on coal FABA from Suralaya power plant, the grain size of coal bottom ash from Suralaya power plant has been researched, and the result is presented in Fig. 1. Fig. 1 shows that 71% of the coal bottom ash passes through 2.36 mm sieve, 49% of the coal bottom ash passes through 1.18 mm sieve, 26% of the coal bottom ash passes through 0.6 mm or 600 µm sieve, and 15% of the coal bottom ash passes through 0.3 mm or 300 µm sieve. Therefore, based on those percentages, coal bottom ash from Suralaya power plant could be classified as grade M sand according to BS 882: 1973.

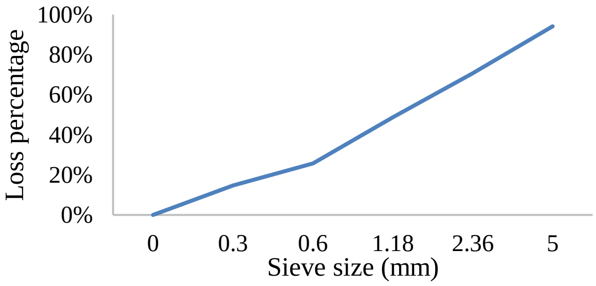

Fig. 1 Sieve analysis of Suralaya power plant bottom ash

This research procedure was divided into several steps presented in Fig. 2. The research steps are the slump test, compressive strength test, flexural strength test, and carbon footprint analysis. The concrete mixture tested in this research are conventional concrete, control concrete (CC), and concrete with coal FABA content. The concrete with coal FABA content was further divided into concrete with fly ash mixture or fly ash concrete (FAC), concrete with bottom ash mixture or bottom ash concrete (BAC), and concrete with fly ash and bottom ash mixture or fly ash and bottom ash concrete (FABAC).

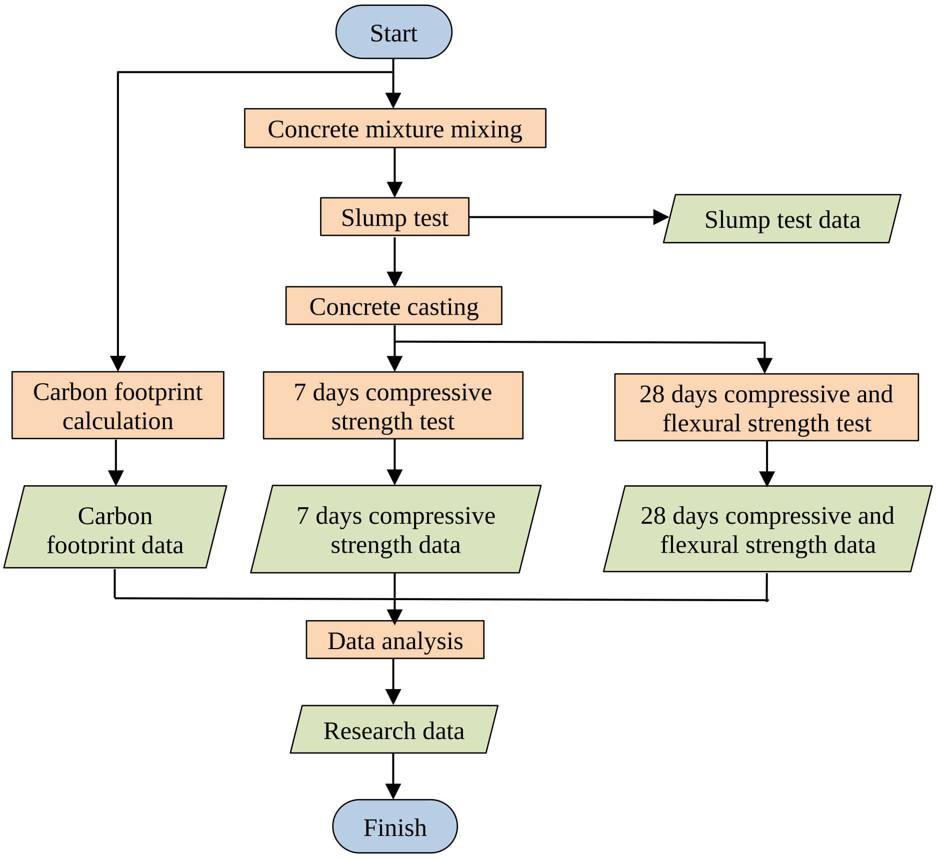

Fig. 2 Research procedure

Table 2 Concrete material proportion

Concrete mixture type	Material proportion					
	Fly ash (kg)	Cement (kg)	Bottom ash (kg)	Sand (kg)	Coarse aggregate (kg)	Water (kg)
CC	0	448	0	667	1000	215
FAC I	179	269	0	667	1000	215
FAC II	448	0	0	667	1000	215
BAC I	0	448	267	400	1000	215
BAC II	0	448	667	0	1000	215
FABAC I	179	269	267	400	1000	215
FABAC II	448	0	667	0	1000	215

This research designed CC with a compressive strength of 31.2 MPa at 28 days with a 10-14 cm slump range. On FAC I, 40% of the cement mass was substituted with coal fly ash; on FAC II, cement was entirely substituted with coal fly ash. On BAC I, 40% of the sand mass was substituted with coal bottom ash; on BAC II, sand was wholly substituted with coal bottom ash. On FABAC I, 40% of the cement mass was substituted with coal fly ash, and 40% of the sand mass was substituted with coal bottom ash. On FABAC II, cement was entirely substituted with coal fly ash, and sand was entirely substituted with coal bottom ash. The 40% and 100% mass replacement for cement and sand was chosen to test whether or not such replacement values were possible to create concrete with equal or slightly lower strength than conventional concrete that produces a considerably lesser amount of CO_2 emission. The material proportion of each concrete mixture is presented in Table 2.

The slump test was done for each concrete mixture according to SNI 03-1972-1990. The concrete mixes were then cast for compressive strength and flexural strength tests. The compressive strength test was done with six 150 × 150 × 150 mm cubes for each concrete mixture, and the compressive strength was tested at the concrete age of 7 and 28 days. The flexural strength test was done with three 530 × 150 × 150 mm beams for each concrete mixture, and the flexural strength was tested at the age of 28 days. Finally, the water quality change test was done with three concrete shapes, curb, paving block, and concrete road.

During its life cycle, concrete goes through several phases presented in Fig. 3. While each phase produces its CO_2 emission, carbon footprint calculation in this research is limited to the material production and extraction phase and material transport phase. The CO_2 emission in the concrete usage phase, concrete maintenance phase, and end-of-life phase are not analyzed because conventional concrete and coal FABA do not have different processes in those phases and are assumed to produce equal amounts of CO_2 emission. The CO_2 emission was calculated from 1 m^3 of concrete production.

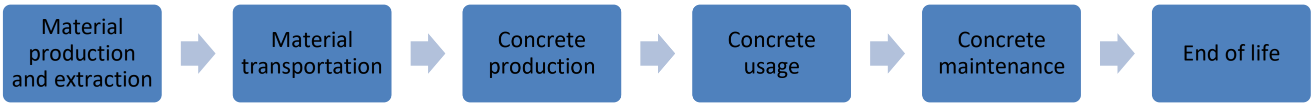

Fig. 3 Life cycle of concrete

3. Results and Discussion

3.1. Slump test result

In this research, the slump test was done on every concrete mixture according to SNI 03-1972-1990; therefore, the slump test was done twice for each concrete mixture. The slump of each concrete mixture was then obtained by calculating the average slump of the two slump tests. The slump test result obtained in this research is presented in Fig. 4.

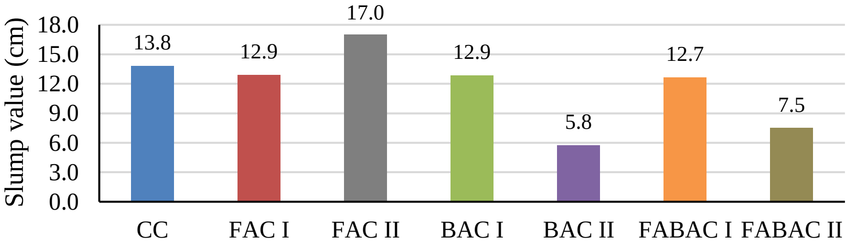

Fig. 4 Slump test result

From the result shown in Fig. 4, only CC, FAC I, BAC I, and FABAC I meet the expected slump value of 10 to 14 cm. On the contrary, FAC II obtained the highest slump value with a slump value of 17 cm, which is significantly higher than CC. While complete substitution of cement with coal fly ash done in FAC II results in a higher slump value than CC, partial substitution of cement with coal fly ash done in FAC I results in a lower slump value than CC. According to [22], fly ash reacts with $Ca(OH)_2$ released from the hydration of cement in the concrete and produces cementing materials. The resulting cementing materials from the reaction between SiO_2 and $Ca(OH)_2$ would increase the cementing material in concrete more than conventional concrete. Therefore, the absence of cement in FAC II means there is no reaction between coal fly ash with $Ca(OH)_{2,}$ and the coal fly ash cannot bind the coarse aggregate and fine aggregate, which causes a higher slump value. On FAC I, the reaction between coal fly ash and $Ca(OH)_2$ creates more cementing material, which causes slump value decrement.

Both BAC I and BAC II show a lower slump value than CC. While partial substitution of sand with coal bottom ash in BAC I still gives an acceptable slump value of 12.9 cm, the complete substitution of sand with coal bottom ash on BAC II results in a significantly lower slump value of 5.8 cm. The slump value of BAC II of 5.8 is also the lowest of other concrete mixtures. This result shows that the increment of bottom ash content in a concrete mixture will cause a higher slum value reduction.

The slump value of FABAC I and FABAC II are lower than CC. While FABAC I slump value of 12.6 cm still meets the expected slump value, FABAC II, with a slum value of 7.5 cm, does not. The slump value decrement in FABAC I, which is lower than FAC I and BAC I shows that both partial substitution s of cement with coal fly ash and partial substitution of sand with coal bottom ash contribute to the slump value decrement. The contribution of coal FABA content could also be seen on FABAC II, which has the same amount of coal fly ash as FAC II and bottom ash as BAC II. In this case, the high coal bottom ash content decreases the slump value of FABAC II. However, the lack of reaction between coal fly ash with $Ca(OH)_2$ decreases the effect of slump value reduction, causing it to obtain a slump value of 7.5 cm, which is higher than BAC II but still lower than CC.

3.2. Compressive strength

The compressive strength test was done at the concrete age of 7 and 28 days. Three concrete cubes were tested at the age of 7 days, and three were tested at 28 days for each concrete mixture. The average value of the results was calculated to obtain the compressive strength value at the age of 7 days and 28 days. From the seven concrete mixtures made, FAC II and FABAC II could not be tested due to the lack of hardening from the absence of cement on those mixtures. Therefore, no hardening on FAC II and FABAC II shows that complete cement substitution with coal fly ash is not viable for creating concrete. The compressive strength result from this research is presented in Fig. 5.

Fig. 5 shows that the compressive strength of CC at the age of 28 days is 31 MPa, slightly lower than the designed compressive strength of 31.2 MPa. The figure also shows that coal fly ash on FAC I and coal bottom ash on BAC I, BAC II, and FABAC I decrease the concrete's compressive strength at seven and 28 days. Between the concretes that contain coal fly ash, coal bottom ash, or both coal fly ash and coal bottom ash, at the age of 7 days BAC I shows the highest compressive strength of 18.9 MPa, followed by FABAC I with 17.9 MPa, BAC II with 16.5 MPa, and FAC I with 13.2 MPa. This result also means that at seven days, BAC I reaches 91% of CC compressive strength of the same age, while FABAC I reaches 87%, BAC II reaches 80%, and FAC I reaches 64%.

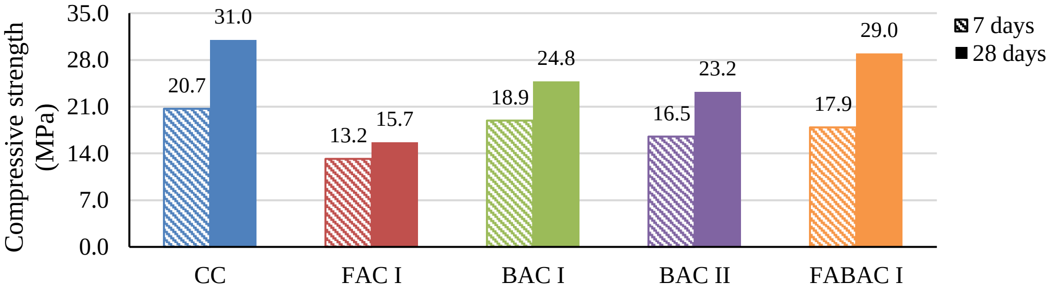

Fig. 5 Compressive strength result

At 28 days, FABAC I shows the highest compressive strength of 29 MPa, BAC II with 23.2 MPa, BAC I with 24.8 MPa, and FAC with 15.7 MPa. Compared to CC compressive strength of the same age, FABAC I reach 94% of CC compressive strength while BAC II reaches 80%, BAC I reach 75%, and FAC reaches 51%. The amount of compressive strength increment can also be seen in Fig. 5. At the age of 7 days, CC reaches 67% of its compressive strength at 28 days, while FAC I reaches 84%, BAC I reaches 76%, BAC II reaches 71%, and FABAC I reach 62%. These results show that coal FABA affects compressive strength gain on the concrete.

The result of this research also shows that concrete with FABA content has a lower compressive strength of both seven days and 28 days in this research shows that concrete with coal FABA from Suralaya power plant has lesser compressive strength than conventional concrete. This strength decrement could be attributed to several factors. The strength decrement on FAC I and FABAC I could happen due to cementing material created from SiO2 and Ca(OH)2 having lesser quality than cementing material from the reaction between water and cement in conventional concrete. The lower compressive strength could also occur due to the higher amount of air and water gap in the concrete due to the lesser workability of the concrete mixture from the lower slump value of FAC I, BAC I, BAC II, and FABAC I. The BAC I, BAC II, and FABAC I concretes in this research have higher compressive strength than 20 MPa and still meet the minimum requirements of structural concrete. However, more research would be needed to guarantee that concrete with coal FABA is safe for structural concrete.

3.3. Flexural strength

In this research, the flexural strength test was done at the concrete age of 28 days. Three concrete beams were tested at 28 days for each concrete mixture. The average value of the results was calculated to obtain the flexural strength value. Like the compressive strength test, FAC II and FABAC II could not be tested due to the lack of hardening from the absence of cement on those mixtures. The flexural strength result from this research is presented in Fig. 6.

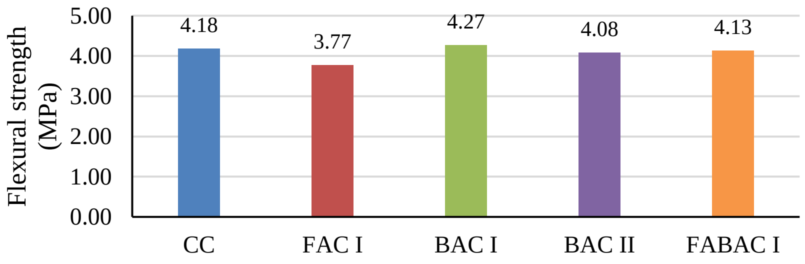

Fig. 6 Flexural strength result

Fig. 6 shows that coal FABA content within concrete affects flexural strength. The highest flexural is obtained by BAC I, with a flexural strength of 4.27 MPa. This flexural strength is higher than CC, with a flexural strength of 4.18 MPa. While BAC I shows that partial substitution of sand with coal bottom ash could increase the flexural strength of concrete, BAC II, with a flexural strength of 4.03 MPa, shows that complete substitution would reduce the flexural strength. The result also shows that partial cement substitution with coal fly ash would reduce the flexural strength of concrete. This is proven in FAC I with a flexural strength of 3.77 MPa and FABAC I with a flexural strength of 4.13 MPa. In addition, while the coal fly ash content in FABAC I reduces the flexural strength of the concrete, the coal bottom ash content reduces the flexural strength decrement, making FABAC I flexural strength lower than CC but still higher than FAC I. The result also shows that the higher the compressive strength, the higher its flexural strength is.

3.4. Carbon footprint analysis

This research analyzes the carbon footprint of CC, FAC I, BAC I, BAC II, and FABAC I. The lack of hardening experienced by the FAC II and FABAC II mixture made carbon footprint analysis on those concrete mixtures deemed unnecessary. Therefore, the resulting mixture could not be classified as concrete. The total CO_2 emission in this research was obtained by calculating the CO_2 emission value from the material production and extraction phase and material transportation phase of 1 m^3 of concrete. The precise amount of each material needed to create 1 m^3 of concrete for each concrete type is presented in Table 3.

Table 3 Materials for 1 m^3 of concrete

Concrete type	Material amount					
	Cement (kg)	Sand (kg)	Coarse aggregate (kg)	Water (liter)	Fly ash (kg)	Bottom ash (kg)
CC	448	667	1000	22	0	0
FAC I	269	667	1000	22	179	0
BAC I	448	400	1000	22	0	267
BAC II	448	0	1000	22	0	667
FABAC I	269	400	1000	22	179	267

The amount of CO_2 emission in the material production and extraction phase is affected by each material's amount and their respective production and extraction emission factors. The production and extraction emission factor estimates the amount of CO_2 gas produced in materials' production and extraction process. This research obtains the production and extraction emission factor for cement, sand, coarse aggregate, and fly ash from previous research. In addition, the production and extraction emission factor for water was obtained from the calculation. The production and extraction emission factors of cement and sand for this research are obtained from previous research done by Sudjono and Yudhi [23]. In their study, Sudjono and Yudhi [23] calculate the emission factor of cement as 1.77 kg CO_2/kg cement and the emission factor of sand as 37.97×10^{-2} kg CO_2/kg sand. The coarse aggregate emission factor value is obtained from previous research by Hammond et al. [24] with an emission factor of 1.7×10^{-2} kg CO_2/kg coarse aggregate.

There are several opinions regarding fly ash's production and extraction emission factor. Several pieces of research [25-26] suggest a zero-emission factor for fly ash since fly ash is a waste material produced from coalburning in coal power plants. However, according to Heidrich et al. [27], despite being a waste material, fly ash still produces CO_2 emission since capturing, milling and grinding, drying, and transporting fly ash still use energy and emission factor of 0.027 kg CO_2/kg fly ash was calculated. Currently, the amount of emission factor for bottom ash is not available. Like fly ash, bottom ash is a waste material produced in coal-burning coal power plants and produced together with fly ash. While the amount of bottom ash produced from coal burning is not equal to fly ash, in this research, the emission factor for bottom ash is assumed to be equal to fly ash, which is 0.027 kg CO_2/kg bottom ash.

In this research, water's production and extraction emission factor is calculated assuming that the water was obtained directly at a concrete production location and pumped by a local electric grid powered by a local electric grid. The water is considered to be pumped with a 250-watt water pump with a capacity of 45 L/min. Since this research was done in Bogor, West Java, the electric grid used is Jamali electric grid. According to the Ministry of Energy and Mineral Resources Republic of Indonesia [28], the emission factor of the Jamali electric grid is 0.87 tones CO_2/MWh. The calculation data to obtain the production and extraction emission factor of water is presented in Table 4.

Table 4 Calculation of water production and extraction emission factor

Pump capacity (L/min)	Pump capacity (L/hour)	Pump electric power (watt)	Pump KWh	kWh/L	Grid emission factor (tones CO_2/MWh)	Pump emission factor (kg CO_2/L)
45	2700	250	0.25	9.26×10^{-5}	0.87	8.06×10^{-5}

Using the data in Table 3 and the materials production and extraction emission factor, CO_2 emission of material production and extraction phase could be obtained and presented in Table 5. The data shows that coal FABA content within concrete affects the CO_2 emission of material production and extraction phase. The highest CO_2 emission produced in this phase is made by CC with CO_2 emission of 1064 kg, while the lowest is produced by FABAC I with CO_2 emission of 650 kg. The result also shows that cement substitution with coal fly ash would reduce CO_2 emissions than sand substitution with coal bottom ash. This is proven because FAC I has lower CO_2 emissions than BAC I and II.

Table 5 Material production and extraction phase CO_2 emission

	Material	Amount	Unit	Emission factor	Unit	CO_2 emission (kg)
CC	Cement	448	kg	1.77	kg CO_2/kg cement	794
	Sand	667	kg	37.97×10^{-2}	kg CO_2/kg sand	253
	Coarse aggregate	1000	kg	1.7×10^{-2}	kg CO_2/kg coarse aggregate	17
	Water	22	Liter	8.06×10^{-5}	kg CO_2/L water	0
	Fly ash	0	kg	10^{-2}	kg CO_2/kg fly ash	0
	Bottom ash	0	kg	10^{-2}	kg CO_2/kg bottom ash	0
	Total					**1064**

Table 5 Material production and extraction phase CO_2 emission (continued)

	Material	Amount	Unit	Emission factor	Unit	CO_2 emission (kg)
FAC I	Cement	269	kg	1.77	kg CO_2/kg cement	477
	Sand	667	kg	37.97×10^{-2}	kg CO_2/kg sand	253
	Coarse aggregate	1000	kg	1.7×10^{-2}	kg CO_2/kg coarse aggregate	17
	Water	22	Liter	8.06×10^{-5}	kg CO_2/L water	0
	Fly ash	179	kg	10^{-2}	kg CO_2/kg fly ash	2
	Bottom ash	0	kg	10^{-2}	kg CO_2/kg bottom ash	0
					Total	**749**
BAC I	Cement	448	kg	1.77	kg CO_2/kg cement	794
	Sand	400	kg	37.97×10^{-2}	kg CO_2/kg sand	152
	Coarse aggregate	1000	kg	1.7×10^{-2}	kg CO_2/kg coarse aggregate	17
	Water	22	Liter	8.06×10^{-5}	kg CO_2/L water	0
	Fly ash	0	kg	10^{-2}	kg CO_2/kg fly ash	0
	Bottom ash	267	kg	10^{-2}	kg CO_2/kg bottom ash	3
					Total	**966**
BAC II	Cement	448	kg	1.77	kg CO_2/kg cement	794
	Sand	0	kg	37.97×10^{-2}	kg CO_2/kg sand	0
	Coarse aggregate	1000	kg	1.7×10^{-2}	kg CO_2/kg coarse aggregate	17
	Water	22	Liter	8.06×10^{-5}	kg CO_2/L water	0
	Fly ash	0	kg	10^{-2}	kg CO_2/kg fly ash	0
	Bottom ash	667	kg	10^{-2}	kg CO_2/kg bottom ash	7
					Total	**818**
FABAC I	Cement	269	kg	1.77	kg CO_2/kg cement	477
	Sand	400	kg	37.97×10^{-2}	kg CO_2/kg sand	152
	Coarse aggregate	1000	kg	1.7×10^{-2}	kg CO_2/kg coarse aggregate	17
	Water	22	Liter	8.06×10^{-5}	kg CO_2/L water	0
	Fly ash	179	kg	10^{-2}	kg CO_2/kg fly ash	2
	Bottom ash	267	kg	10^{-2}	kg CO_2/kg bottom ash	3
					Total	**650**

The amount of CO_2 emission in the material transportation phase is affected by the transport vehicle emission factor and the total distance between the material source and concrete production location. The transport vehicle emission factor could be calculated by knowing the emission factor of the fuel, fuel heat value, and vehicle fuel consumption. According to IPCC standards for mobile combustion [29], the CO_2 emission factor for diesel oil is 74100 kg/TJ. Since this research was done in Indonesia, the fuel heat value was obtained from the national standard. The heat value of solar fuel in Indonesia is 3.60×10^{-5} TJ/Liter [30]. The transport vehicles used for every material in this research are trucks with a 6 m^3 or two tones transport capacity, with a fuel consumption ratio of 6.5 liters for each km. The transport vehicle's emission factor is presented in Table 6.

Table 6 Transport vehicle emission factor

CO_2 emission factor (kg/TJ)	Fuel heat value (TJ/L)	Fuel consumption ratio (km/L)	Vehicle emission factor (kg CO_2/km)
74100	3.60×10^{-5}	6.5	0.41

The total distance between material source and concrete production location for each material is obtained by calculating the distance between material source and concrete production location and the number of trips the transport vehicle needs to satisfy the amount of material required for 1 m^3 of concrete. In this research, the concrete production location is assumed to be in Bogor, West Java. The sand, coarse aggregate, and cement used are obtained from the nearest source to the concrete production location. Water is assumed to be pumped directly into the concrete production location. Therefore, the total distance for water is zero. Coal FABA are transported from Suralaya Coal Power Plant in Cilegon, Banten. The vehicles used to transport the materials in this research are assumed to have a capacity of 6 m^3 or two tons. Since the amount of materials needed for 1 m^3 of concrete is below the vehicle's maximum capacity, the trip number for all materials is 1. The detail of the total distance calculation is presented in Table 7.

Table 7 Transport vehicle total distance

Material	Distance (km)	Trip	Total distance (km)	Source
Cement	20	1	20	Cement plant in Mayor Oking Jayaatmaja Street, Citeureup Village, Citeureup Sub-district, Bogor District
Sand	34	1	34	Sand and stone mine Pasir Buncir Village, Caringin Sub-district, Bogor District
Coarse aggregate	34	1	34	
Water	0	0	0	On site
Fly ash	152	1	152	Suralaya Coal Power Plant in Cilegon, Banten
Bottom ash	152	1	152	

Table 8 Material transportation phase CO_2 emission

	Material	Total distance	Unit	Emission factor	Unit	CO_2 emission (kg)
CC	Cement	20	km	0.41	kg/km	8
	Sand	34				14
	Coarse aggregate	34				14
	Water	0				0
	Fly ash	0				0
	Bottom ash	0				0
	Total					**36**
FAC I	Cement	20	km	0.41	kg/km	8
	Sand	34				14
	Coarse aggregate	34				14
	Water	0				0
	Fly ash	152				62
	Bottom ash	0				0
	Total					**98**
BAC I	Cement	20	km	0.41	kg/km	8
	Sand	34				14
	Coarse aggregate	34				14
	Water	0				0
	Fly ash	0				0
	Bottom ash	152				62
	Total					**98**
BAC II	Cement	20	km	0.41	kg/km	8
	Sand	0				0
	Coarse aggregate	34				14
	Water	0				0
	Fly ash	0				0
	Bottom ash	152				62
	Total					**84**
FABAC I	Cement	20	km	0.41	kg/km	8
	Sand	34				14
	Coarse aggregate	34				14
	Water	0				0
	Fly ash	152				62
	Bottom ash	152				62
	Total					**161**

The amount of CO_2 emission in the material transportation phase could be calculated by calculating the transport vehicle emission factor and total distance. The amount of CO_2 emission from each concrete type in this phase is shown in Table 8. According to the result, the highest CO_2 emission produced in this phase is made by FABAC I, with CO_2 emission of 161 kg.

On the other hand, the lowest CO_2 emission was created by CC, with CO_2 emission of 36 kg. The high amount of CO_2 emission produced by FABAC I is caused by the high distance needed to transport coal FABA from the Suralaya Coal Power Plant in Cilegon to Bogor. The distance between those 2 locations is 151.8 km, the highest distance compared to other materials. On the other hand, CC produces low CO_2 emissions due to the short distance needed to transport materials, with the highest distance for sand and coarse aggregate of 34 km.

By knowing the amount of CO_2 emission from the material production and extraction phase and material transportation phase, the total CO_2 emission could be calculated. Fig. 7 shows the CO_2 emission amount produced by each concrete type. The result shows that CC produces the highest CO_2 emission while FABAC I produces the lowest CO_2 emission. This indicates that despite the high distance from the source of coal FABA, their utilization as concrete material still produces less CO_2 emission than conventional concrete. This result could be improved even further if the concrete production location is closer to Suralaya Coal Power Plant. Finally, the distance between Suralaya Coal Power Plant to concrete production location in Bogor is the main factor that causes high CO_2 emission of FABAC I in the material transport phase.

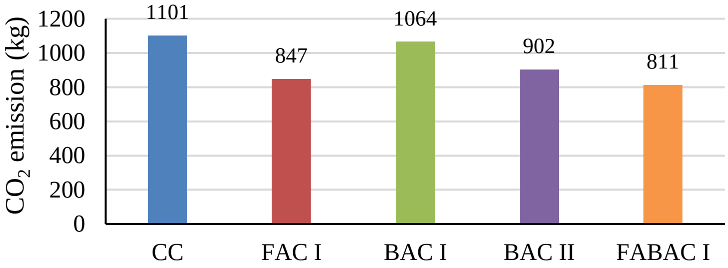

Fig. 7 Total CO_2 emission of the concrete mixtures

4. Conclusions

In this study, the analysis of coal FABA was conducted, and the slump value, compressive strength, flexural strength, and carbon footprint of the conventional concrete and the concrete with coal FABA content were obtained. From these results, the conclusions regarding the potential of coal FABA from Suralaya Coal Power Plant as concrete material and its environmental impact are as follows:

(1) The slump test shows that concrete with coal FABA, in general, has a lower slump value than conventional concrete, therefore, decreasing the workability of the coal FABA concrete mixture.

(2) The compressive strength test result shows that concretes with coal FABA have lower compressive strength than conventional concrete and be better suited for a non-structural component.

(3) The flexural strength test result shows that concrete with coal FABA has lower flexural strength than conventional concrete, and this decrement should be considered in its usage in buildings.

(4) Carbon footprint calculation shows that concrete with coal FABA content produces less CO_2 emission and therefore has lesser environmental impact than conventional concrete.

Conflicts of Interest

The authors declare no conflict of interest.

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