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Use of Coal Waste as Fine Aggregates in Concrete Blocks for Paving

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Summary

Brazilian run-of-mine (ROM) coal contains high levels of impurities (rock minerals and pyrite). Thus, it requires concentration methods to reach the conventional Brazilians power station's standards, which require coals containing 43% of ash and 2.3% of sulphur. Approximately, 65% of the ROM material is discharged in waste deposits. It is estimated that more than 300 million tons of coal waste exists in the south of Brazil, generating AMD with the well-known environmental impacts and economic costs.

By means of gravity beneficiation of the coarse and fine solid wastes from coal mining is possible to obtain three different densimetric fractions: (a) a fraction with high density rich in pyrite; (b) a fraction with low density that could be used in thermoelectric plants which accepts coals with high levels of ashes; and (c) a fraction of intermediate density that is composed mainly by sedimentary rock (shale and siltstone) with a low sulfur content.

The fraction of intermediate density accounts with 44% of the waste material and can be potentially used to replace conventional aggregates in pavement blocks production. Thus, the aim of this work was to study the use of coal waste to produce concrete blocks for paving.

The methodology of the study considered the following steps: (a) sampling of mining wastes from gravimetric beneficiation of the coal layer Barro Branco (Santa Catarina, Brazil); (b) gravity separation of material with density between 2.4 and 2.8; (c) comminution of the material and particle size analysis; (d) technological characterization of the material and production of concrete blocks for paving using coal mine waste as fine aggregate.

Concrete blocks were produced with coal waste replacing sand in 0%, 25%, 50%, 75%, and 100%. The compressive strength was evaluated in the concrete blocks at 7, 28, and 90 days. Static tests by acid-base accounting methods were carried out to evaluate the environmental aspects (i.e. acidity generation) of the concrete blocks.

The results showed that the coal waste considered in this work can be used to replace conventional sand as a fine aggregate for concrete blocks pavements. According to statistic tests (ANOVA), blocks made with 25% and 50% of coal waste replacing silica sand presented

the same mechanical strength of the reference blocks (0% of substitution) and are environmentally safety.

Significant environmental gains are expected. The demand by sand deposits in southern Brazil can be minimized and part of coal tailings can be used, reducing the volume in coal waste deposits. This practice can collaborate in clean coal production and help the economic and social development within the regional context.

Keywords: coal waste, acid mine drainage (AMD), fine aggregate, concrete block paving

1. Introduction

The beneficiation of coal for down-stream use generates large quantities of solid waste. These wastes can lead to the formation of acid mine drainage (AMD), a source of ground and surface water pollution. In Brazil, the coal industry currently emphasizes an end-of-pipe approach to waste disposal and mitigation of AMD impacts which represent a long-term cost to the coal producers. However, more preventive approaches accordingly with cleaner production and sustainable development principles can assist the mining industries to decrease both costs and environmental impacts (Hilson, 2003; Reddick, 2008; McLellan et al., 2009; Haibin e Zhenling, 2010).

About 65% of the ROM coal produced in Santa Catarina, Brazil, is deposited in landfills and/or dump deposits as waste. By processing of coal wastes is possible to find three output streams: (i) a low density and more carbonaceous waste; (ii) intermediated density and lower sulphide stream; and (iii) a high density and pyrite-rich stream. The intermediated relative density material represents about 40-50% in mass of a typical coal waste deposit and in it is typically composed by quartz, other silicates and carbonates (Amaral Filho, 2009).

The productive chain of civil engineering uses huge amounts of raw material implicating in several environmental impacts. Consequently, the minestone utilization in civil engineering has been studied and it can be applied in many fields. Canibaño (1995) demonstrated feasibility using coal wastes as a filling material in reinforced earth structures and capping layers of roads (base and subbase). Skarzynska (1995) presents descriptions of minestone applications to hydraulic, harbor, and road engineering as well as to mine backfilling and restoration of derelict land. Lemeshev et al. (2004) showed that building ceramic materials can be produced using coal-mining waste in Russia.

Segmented paving blocks are worldwide utilized and can be used in a large range of applications. Previous research has shown that is it possible to use some wastes to produce concrete blocks (Leenders, 1984; Hood, 2006; Pagnussat, 2004; Vargas, 2002). Thus, the aim of this work was to study the use of coal waste to produce concrete blocks for paving. The paper evaluates the technical and environmental feasibility of this technology and it is focused on recycling the coal waste and to turn it into a useful product.

2. Materials and experimental program

Coal waste studied comes from a typical coal waste deposit located in Criciúma, Santa Catarina, Brazil. After ROM coal processing, the waste is placed at a dump deposit. The estimated waste mass in the deposit is 14 million tons.

Samples were collected from four drill holes in the waste deposit, mixed and quartered. The sample was screened to separate the "coarse" fraction (-50.8mm + 2.0mm), "fine" fraction (-2.0mm +0.5mm) and the "ultra-fine" fraction (-0.5 mm),. The "coarse" and "fine" fractions were submitted to a laboratory dense medium tests in accordance with Brazilian National Standards (ABNT) method 8738:1985 (ABNT, 1985) aiming to obtain a fraction with relative densities between 2,4 and 2,8.

Size particle distribution adjust by milling was carried out to turn coal waste into recycled fine aggregate (RFA). The material was screened in accordance to ABNT method 7211:2009 (ABNT, 2009), which defines the limits of size particle distribution of fine aggregates in Brazil.

The characterization studies of the RFA included: (a) particle size distribution, in accordance to ABNT method 7211:1983 (ABNT, 1983); (b) X ray diffraction (XRD) to assess the mineralogical composition by means of XRD analyser, Siemens, model D5000; (c) elementar analyses (C, H, N, S) by means of Elementar Vario Macro; (d) ash, in accordance with ABNT method NBR 8289:1983 (ABNT, 1983a); (e) humidity, in accordance with ABNT method NBR 8293:1983 (ABNT, 1983b); (f) volatile matter, in accordance with ABNT method NBR 8290:1983 (ABNT, 1983c); and (g) forms of sulfur; in accordance with International Organization for Standardization (ISO) method 157:1996 (ISO, 1996). In order to classify the RFA about its potential risks to the environment and public health was carried out both characterization and classification according to ABNT method 10004:2004 (ABNT, 2004).

The feasibility of its application as a substitute for natural fine aggregate in concrete was investigated through the production of specimens of concrete blocks for paving. The design of experiment was developed in order to determine if there is a statistically significant difference between the specimens with different amount of RFA in its composition. The statistical technique used to evaluate the size of the difference between sets of scores was the Analysis of variance (ANOVA). The response variable chosen was compressive strength. The controllable sources for the compressive strength experiment were the amount of RFA in substitution in weight of natural fine aggregate (0%, 25%, 50%, 75% and 100%) and the curing period (7, 28 and 90 days). It was produced 6 block specimens per curing time. In order to test the difference between the averages the significance level considered was 5%. Further information about ANOVA can be found in Montgomery (2001).

The concrete was produced in a vertical shaft concrete mixer. The specimens were produced in a manual vibro press machine with low vibration through a 03 hp three-phase motor and with a production capacity of six blocks per cycle. Vibration and pressing lasted 30 seconds in each cycle of production.

ABNT method 9781:1987 (ABNT, 1987) establishes at least 35 MPa in the compression resistance for concrete blocks for paving. Preliminary tests were performed to establish the proportion of materials in concrete to reach satisfactory compression strength. The mix prepared with 10,726 kg cement, 12,511 kg coarse aggregate, 28,362 kg fine aggregates and 3,708 kg water (water/cement ratio of 0.35) produced specimens with average resistance 37, 4 MPa at 28 days.

The substitution of natural fine aggregate for RFA was carried out in volume to keep the same conditions to each mix to a same volume of concrete. It was necessary due to the difference of specific mass between the natural fine aggregate (2, 63 g/cm^3) and the RFA (2, 24 g/cm^3). Specific masses were determined in accordance with ABNT method 52:2009 (ABNT, 2009). The adjustment of the equivalent mass to the percentage of equivalent fine aggregate is given by the formula:

mRFA = (ɣRFA/ɣA) x mA x %Substitution, where:

mRFA = mass of RFA (in kg) corresponding to the percentage of substitution over the volume of fine aggregate;

ɣRFA/ɣA = relation between specific masses of RFA (ɣRFA) and natural fine aggregate (ɣA);

mA = mass of natural fine aggregate (in kg);

%Substitution = content of substitution of natural fine aggregate per RFA (25, 50, 75 or 100%).

The method used to establish the water/cement (w/c) ratio for the production of specimens in each percentage of substitution is the pellet test, as used by Tango (1994), Vargas (2002), Pagnussat (2004) and Hood (2006). The pellet test is used to verify the optimum moisture content, which corresponds to the maximum possible amount of water present in the mixture. It consists of molding a concrete pellet in hands. The pellet should not dismantle or get hand dirty.

The w/c relation could not be kept for all the different percentage of substitution because RFA presents higher water absorption than the natural fine aggregate. Thus the higher the percentage of substitution higher was the water cement ratio. Table 1 shows the w/c ratio used in the concrete produced with each percentage of substitution of natural aggregate for RFA.

Table 1. Water/cement ratio used in each percentage of substitution

% of substitution	w/c ratio
0%	0,35
25%	0,37
50%	0,39
75%	0,43
100%	0,44

Compression tests were performed according to ABNT method 9780:1987 (ABNT, 1987). Mortar capping of specimens was conducted before the compression test to get a perfect plain surface.

Finally, the acid generation potential of the raw waste, RFA, and pave blocks was carried out by the traditional method of accounting for acids and bases (ABA) (Sobek, 1978; EPA, 1994). The objective was to determine the balance between the production of acidity (AP) and consumption of acidity - neutralization (NP), by the mineral components of the sample.

3. Results and discussions

Figure 1 presents particle size distribution of RFA and the ABNT method 7211:1983 (ABNT, 1983) requirements. It is observed that the aggregate produced from coal waste can be processed and reach the Brazilian specifications for fine aggregates.

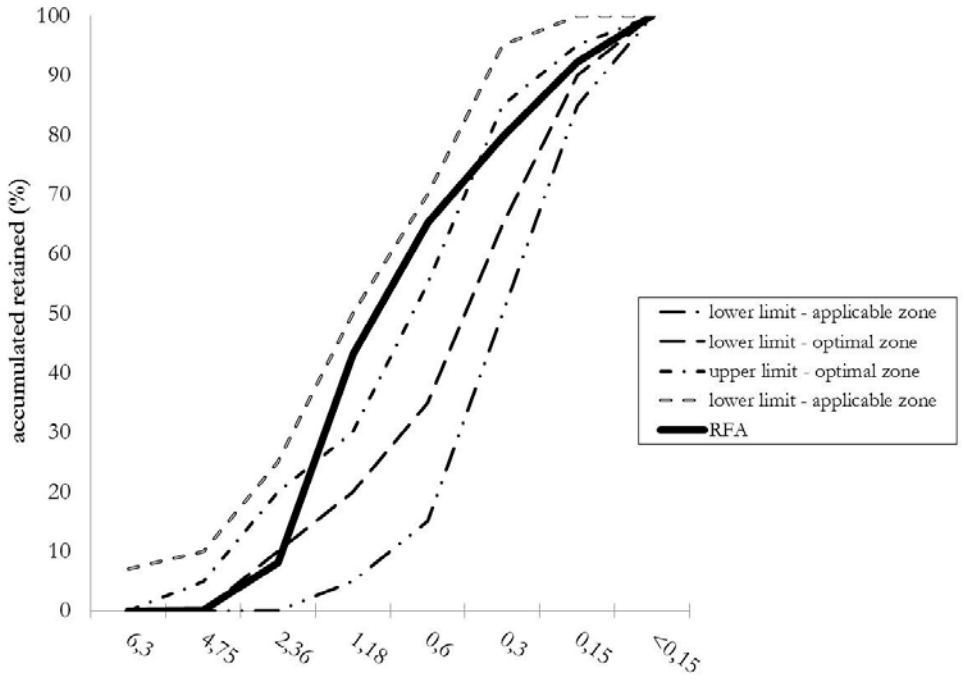


Figure 1. Size particle distribution of RFA and the Brazilian standards for the lower and upper limits

Figure 2 presents the mineralogical findings to RFA obtained. The major mineral phase found is quartz (SiO_2). The minor components included kaolinite ($Al_2Si_2O_5(OH)_4$), gypsium ($CaSO_4.2H_2O$) and illite ($(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$).

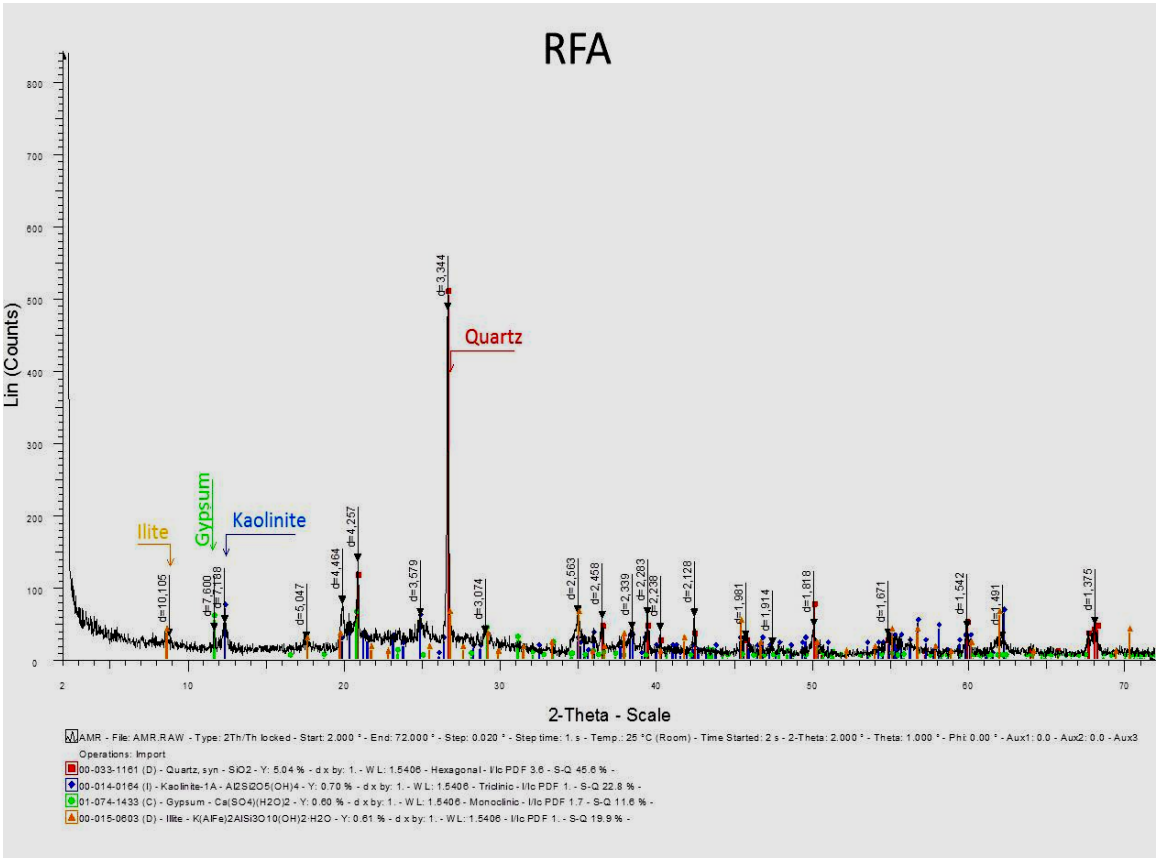


Figure 2. Mineralogic composition of the RFA

Table 2 shows the results of elemental and immediate analysis in of the raw waste and of the RFA. It can be seen that RFA shows a lower concentration of sulfur and carbonaceous material due to the densimetric separation. The ash content in RFA is 90%. It indicates the predominance of compounds thermally stable in the material (mineral matter). Additionally, the RFA was classified as a non-hazardous solid waste (class II-A, non-inert) according to the Brazilian NBR 10004:2004 (ABNT, 2004) test.

Table 2. Immediate analysis of RFA

RFA	
Volatile matter (%)	9,6
Ash (%)	90,0
Humidity (%)	0,6
Total S (%)	1,95
Pyritic S (%)	1,10
Sulfatic S (%)	0,54
Organic S (%)	0,30

Figure 3 presents average compression strength obtained in each curing period and percentage of substitution of sand for RFA. ANOVA table is presented in Table 3. All factors and their interaction showed significant differences.

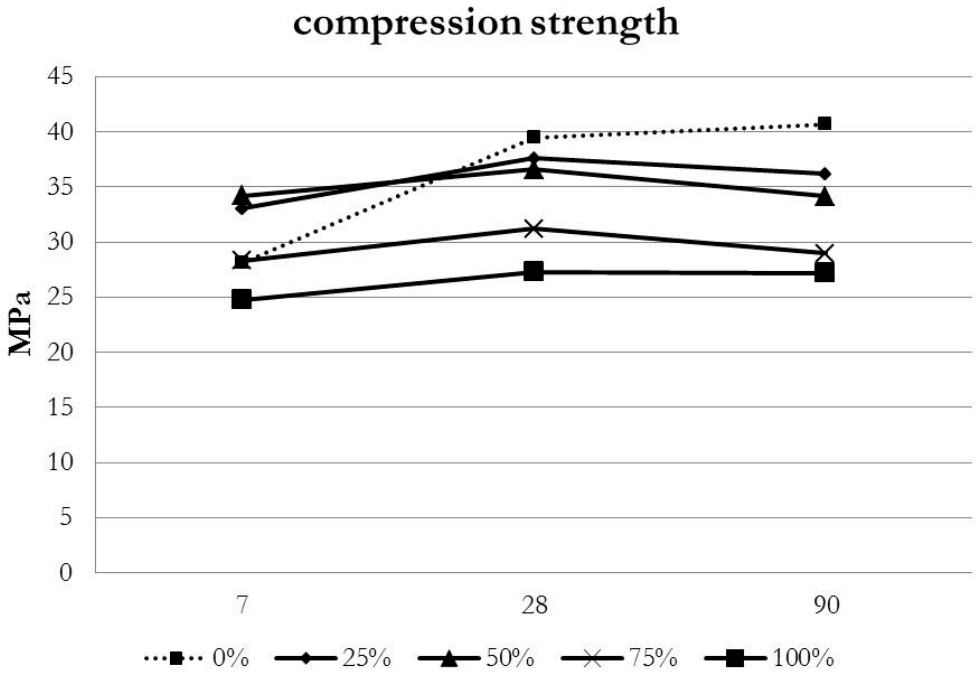


Figure 3. Average compressive strength of the concrete blocks for paving

Table 3. ANOVA of compressive strength of specimens

Source	Sum of Squares	Degrees of freedom	Mean square	F test	F tab	significance
curing period	376	2	188	17,84	3,12	significant
% of substitution	1339	4	335	31,75	2,49	significant
curing period * % of substitution	345	8	43	4,09	2,06	significant
Error	791	75	11			
SQT	2851	89				

Tukey's multiple comparison test was conducted to see which percentage of substitution means are different. At 28 days of curing the difference between reference blocks (0% of substitution), 25% blocks and 50% blocks was not significantly. At 90 days of curing the reference blocks showed significant difference among other blocks produced with RFA. Table 4 presents Tukey's multiple comparison test results.

Table 4. Tukey's multiple comparison test

% of substitution	Compression strenght[1] (MPa)		
	7 days	28 days	90 days
0	28,1 ± 2,794[a]	39,5 ± 2,92[a]	40,7 ± 0,27[a]
25	33,0 ± 3,37[b]	37,6 ± 1,58[a]	36,2 ± 5,25[b]
50	34,2 ± 1,35[b]	36,6 ± 1,40[a]	34,1 ± 4,38[b]
75	28,3 ± 1,56[a]	31,2 ± 2,70[b]	29,0 ± 3,78[c]
100	24,8 ± 4,57[a]	27,3 ± 3,11[b]	27,2 ± 4,76[c]

[1]average ± standard deviation.
Values with the same letters compared vertically do not differ significantly from each other.

Table 5 shows the results of static tests of the raw waste, RFA and blocks (0%, 50% and 100% of substitution). According to static tests, raw waste and RFA when exposed to air and water can produce AMD while the blocks do not generate acidity. The low AP and high NP occurred in concrete blocks with 50% and 100% replacement due to high alkalinity of cement. The cement prevents the generation of acidity and stabilizes the waste.

Table 5. Results of static tests

	Raw waste	**RFA**	**Reference Block**	**50% Block**	**100% Block**
Total S (%)	7,0	1,9	0,5	0,9	0,8
AP (kg $CaCO_3$/t)	218,84	60,81	15,73	27,55	23,69
NP (kg $CaCO_3$/t)	0,00	0,00	241,00	488,25	504,23
NNP	-218,84	-60,81	225,27	460,70	480,54
NPR	0,00	0,00	15,32	17,72	21,28
Formation of AMD	Yes	Yes	No	No	No

4. Conclusions

- It was possible to process Brazilian coal waste and obtain a recycled fine aggregate (RFA) that can be used in civil construction.

- Concrete blocks for paving produced with 25% and 50% of RFA in substitution of sand presented satisfactory results in terms of mechanical strength.

- Static test showed that none of the blocks produced with RFA can produce acid mine drainage (AMD).

- The use of coal waste as a fine aggregate for concrete block paving manufacture presents technical viability and environmental benefits.

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