INCORPORATING BOTTOM ASH IN ROLLER COMPACTED CONCRETE FOR COMPOSITE PAVEMENTS

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ABSTRACT
Roller compacted concrete as a pavement material has been gaining acceptance over the past years. RCC can be of particular interest in base course applications combing attractive cost with easiness of construction. RCC is a friendly pavement material to incorporate by-products of industries such as bottom coal ash. This paper presents a laboratory research of RCC mixtures with addition of bottom coal ash for composite pavements. This non-standardized ash was used replacing the natural fine aggregate content. RCC mixtures with cement contents of 80 kg/m^3, 120 kg/m^3 and 160 kg/m^3 were investigated. Other mixtures incorporating various levels of bottom ash were also prepared. Compressive and flexural strength were evaluated for each mixture at 3, 7, 28 and 90 days and modulus of Elasticity was evaluated at 28 and 90 days. The results revealed an increase in flexural strength levels at increasing levels of fine aggregate replacement by bottom ash. A decrease of the order of 15% of cement content was observed at a specified flexural strength level of 2.5 MPa. This study indicates that the addition of bottom ash in RCC mixtures might lead to lower cement contents as well as to a less demand of fine aggregates.

RESUMO
Este trabalho apresenta uma parte dos resultados de uma pesquisa de laboratório sobre a incorporação da cinza pesada no concreto compactado com rolo – CCR, em substituição a areia natural de rio. A cinza utilizada é originada da combustão do carvão na Termoelétrica Jorge Lacerda, localizada em Capivari de Baixo, Santa Catarina. As misturas de CCR foram dosadas com teores de cimento de 80 kg/m^3, 120 kg/m^3 and 160 kg/m^3. A porcentagem total de areia na mistura (22% em peso seco total dos agregados) foi substituída nas proporções de 25, 50, 75 e100%. Foram realizados ensaios de compressão simples e tração na flexão com medida do módulo de deformação. Os resultados obtidos mostraram que a incorporação da cinza pesada melhora as propriedades mecânicas do CCR e que para um valor de resistência à tração de projeto de 2.5 MPa é possível se ter uma economia de até 15% no teor de cimento quando se substitui a areia de rio por 100% da cinza pesada na mistura de CCR.

1. INTRODUCTION

Roller compacted concrete (RCC) was first used as a pavement material in 1930 in Sweden; since then, several examples of successful application of RCC pavements in ports, parking areas, municipal streets, and intersections have been reported (ACI Committee, 1995).

RCC can be used either as the foundation material for base and sub base course of an asphalt surface or as the pavement material itself. The utilization of RCC seems very promising, since it provides pavements with a rigid layer, enhancing the durability of the cover asphalt layer. Roller compacted concrete is a dry mixture of aggregates; water and cementitious materials compacted by vibratory rollers or plate compaction equipment (ACI Committee, 1995). Unlike normal concretes, RCC is consolidated by compaction leading to often low water contents as compared to normal concretes (Nanni et al., 1996).

Nowadays, there is a common concern in bringing sustainability issues to pavement engineering. Several successful examples have been reported in the use of recycled concrete aggregates (Aksnes et al., 2006), recycling porous asphalt (Van de Wall, 2006), and the introduction of secondary materials in asphalt and concrete mixtures. While sustainability issues have become mandatory by some governmental agencies, it is necessary to investigate if such modifications could bring potential economical benefits.

In Brazil, there is an increase need to friendly dispose bottom ash from coal thermal power plants even though the amount produced every year is smaller when compared to the 80 million tons of fly ash and bottom ash produced in the U.S.A. (Ghafoori & Cai, 1998; Golden, 1997).

In 2001, around 2.1 million tons of coal has been consumed by the thermo-electric complex Jorge Lacerda, in Santa Catarina state. Such amount originated 878,286 tons of ashes as an industrial waste, which is equivalent to, approximately, 483,058 tons of fly-ash (55%) and 395,228 tons of bottom ash (45%).Due to its physical-chemical characteristics, the fly-ash is sold to the cement industries that use it in the Pozzolanic Portland Cement or as mineral additions to the concrete. However, the Bottom ash does not reach the same market, becoming a great environmental problem. The current deposit of bottom ash at Jorge Lacerda Thermo-electric plant is estimated in 1.5 million tons, increased by a continuous production of approximately 400,000 tons/year. These deposits are highly aggressive to the local ecosystem. The Figure 1 shows one sedimentation deposit of bottom ash at Jorge Lacerda plant.

Figure 1: Sedimentation deposit of bottom ash at Jorge Lacerda plant.

In pavement engineering, one possible application of bottom ash would be in RCC base course mixtures, in composite pavements. PIARC divides composite pavements into three types:Type 1: a rigid structure (lean or rich concrete) covered with a flexible course (of bitumen); Type 2: a rigid structure covered with modular elements; Type 3: a flexible structure covered with a rigid pavement. The Figure shows the structure composite pavements type 2. In the Figure, are shows the parameters used for composite pavements design.

Bottom ash could be incorporated replacing the fine aggregate content. In this research, RCC will be applied in composite pavements Type 1, this is, the lean concrete (RCC) were covered with a flexible course (of hot mix). The benefits to the environment not only would come due to the use of the waste material, themselves, but also to the less demand of the natural fine aggregate and the better pavement performance (Trichês et al., 2006). This material, however, must be durable and safe against leaching.

This paper presents an on-going laboratory research on the characterization of RCC mixtures with bottom coal ash produced by a Brazilian thermal power plant. Three RCC mixtures with various cement contents (80, 120, and 160 kg/m^3) were proportioned by soil compaction methods. For each mixture, the non-standardized ash was used replacing natural sand content at three levels (25%, 50% and 100%). Flexural strength were performed at various ages.

The results revealed an increase in flexural strength levels of mixtures with high levels of fine aggregate replacement by bottom ash. As such, a certain required level of flexural strength could be achieved by incorporating bottom ash in mixes with less cement content. A cost analysis showed the beneficial effects of such mixtures.

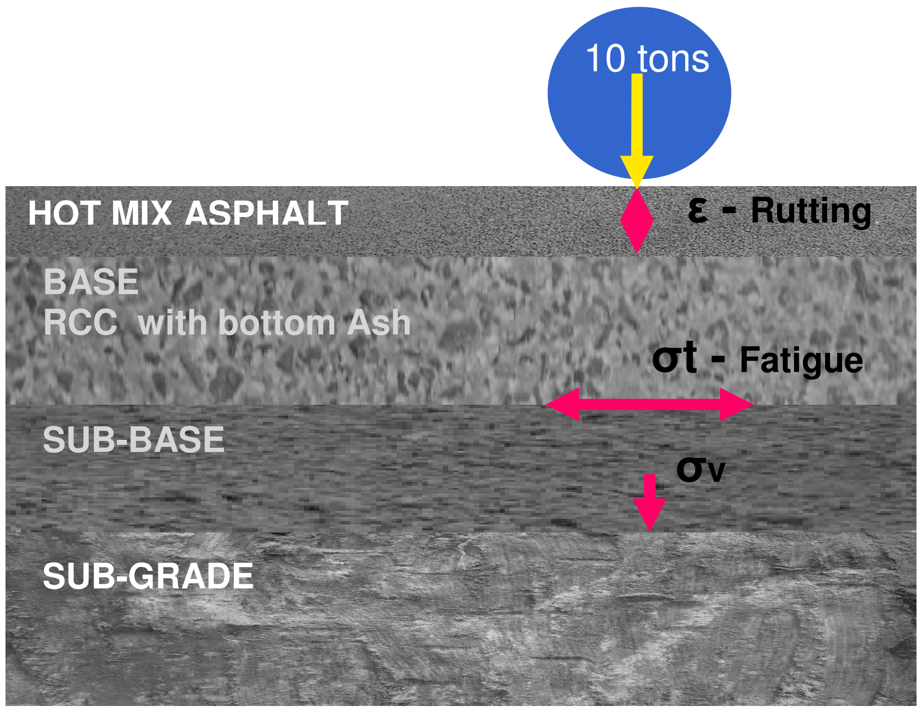

Figure 2: Structure composite pavements type 2.

2. EXPERIMENTAL METHODS AND PRODUCTS

RCC mixture proportions were performed by soil compaction method. Cement and aggregate contents were sought in order to achieve the highest density under compaction. After defining cement content, the ratio between cement and aggregates (in mass) was obtained for various moisture contents according to the following equation:

$$Cc = \frac{1000 - V}{\frac{1}{Dc} + \frac{1}{Dag} + \frac{h(1+m)}{100}} \tag{1}$$

where:

Cc: cement content (kg/m³);
V: voids volume, in liters (approximately 50 L, equivalent to 5% total volume);
m: aggregate / cement ratio (in mass);
h: moisture content (%);
Dc: density of cement (kg/m³); and,
Dag: density of aggregates (kg/m³).

For a fixed cement content (Cc), different amounts of aggregates were obtained by varying the moisture content (h). The optimum moisture content of the mixture was determined from a compaction test. The relationship between bulk density and moisture content of RCC over a range of moisture content was established. The optimum moisture content was the one corresponding to the peak of the moisture-density curve.

RCC mixtures were produced with Brazilian cement CP II – Z, which is a composite cement with pozzolan addition up to 14% in mass. The aggregates were fine river sand, a granite coarse aggregate and bottom ash from a coal-thermal plant. The Table 1 presents the aggregates properties.

Table 1: Aggregates properties.

Aggregates	Density	Los Angeles
Aggregate 1” (25.4mm)	2.66	32.0
Aggregate 3/4” (19 mm)	2.64	
Aggregate 5/8” (9.5mm)	2.59	
Dust stone (< 4.8mm)	2.58	
Bottom ash	1.91	-
Natural sand	2.71	-

The Figure 3 shows coal bottom ash morphology and the chemical composition of the coal bottom ash is presented in Table 2.

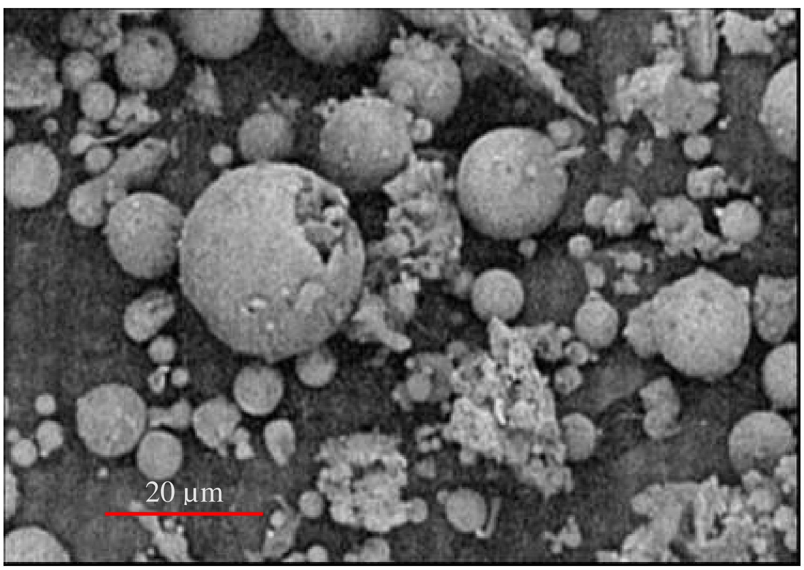

Figure 3: Coal bottom ash morphology.

Table 2: Chemical composition of bottom ash (%).

SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	S	L.O.I.
56,00	26.70	5.80	0.60	0.80	0.20	2.60	1.30	0.10	4.60

The gradation curves for the fine aggregate and bottom ash are presented in Figure 4. Reference mixtures with cement content of 80, 120, and 160 kg/m^3, and fine natural sand content of 22% as the total aggregate mass were initially prepared (RCC 80-0, RCC 120-0, RCC 160-0). Mixtures with bottom ash were produced by replacing with 25, 50 and 100% of natural sand. Aggregate composite gradation curves for all mixtures are presented in Figure 5. Figure 5 also shows the maximum densification gradation as given by the Fuller method with n = 0.45, and maximum aggregate size of 25.4 mm.

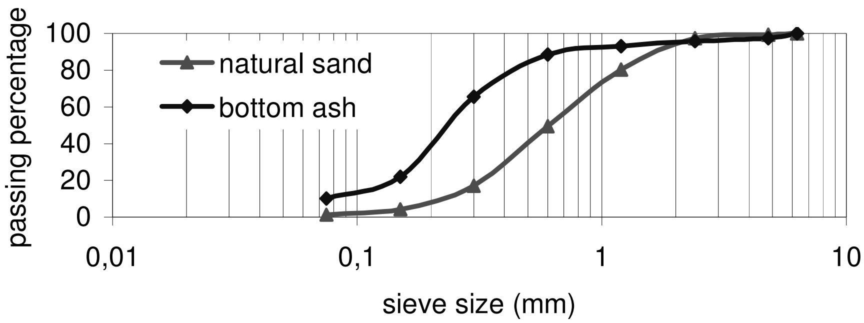

Figure 4: Gradation curves for fine natural sand and bottom ash.

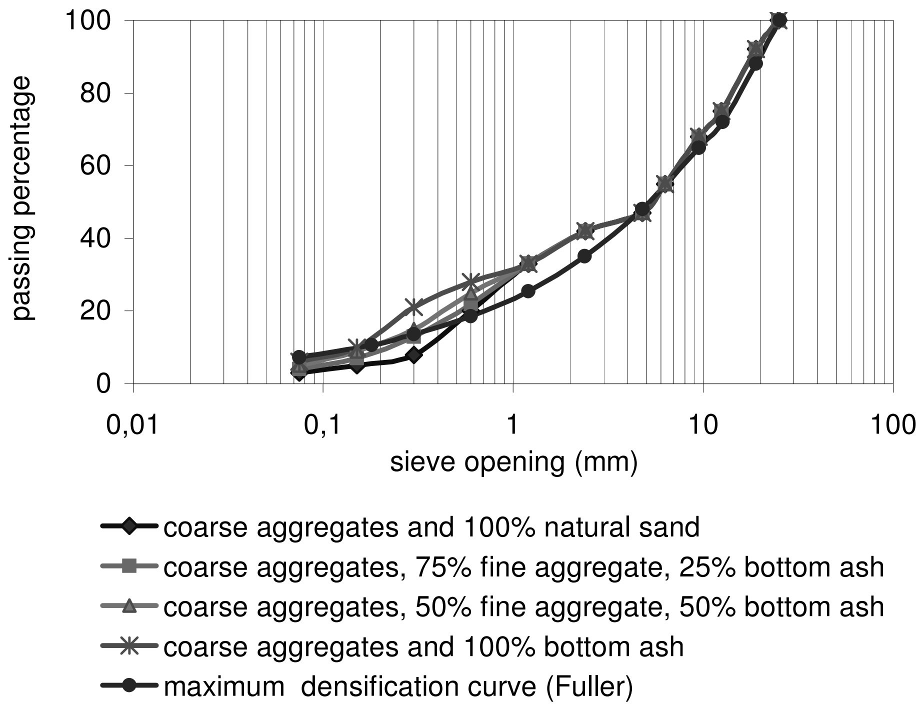

Figure 5: Gradation curves for composite aggregates.

RCC was prepared using the same procedure as for compaction of soils, using a compaction hammer with intermediate Proctor energy. Each mixture was compacted by letting a 4.5 kg mass fall from a 45 cm height. The cylindrical specimens were compacted with seven layers and 65 blonds of hammer per layer (intermediary Proctor energy). The Figure 6 shows the procedure for compacting cylindrical specimen and Figure 7, presents the compaction curves obtained for RCC mixtures with content with cement content 120 kg/m^3 and several levels of sand replacement by bottom ash.

Figure 6: Procedure for compacting cylindrical specimens.

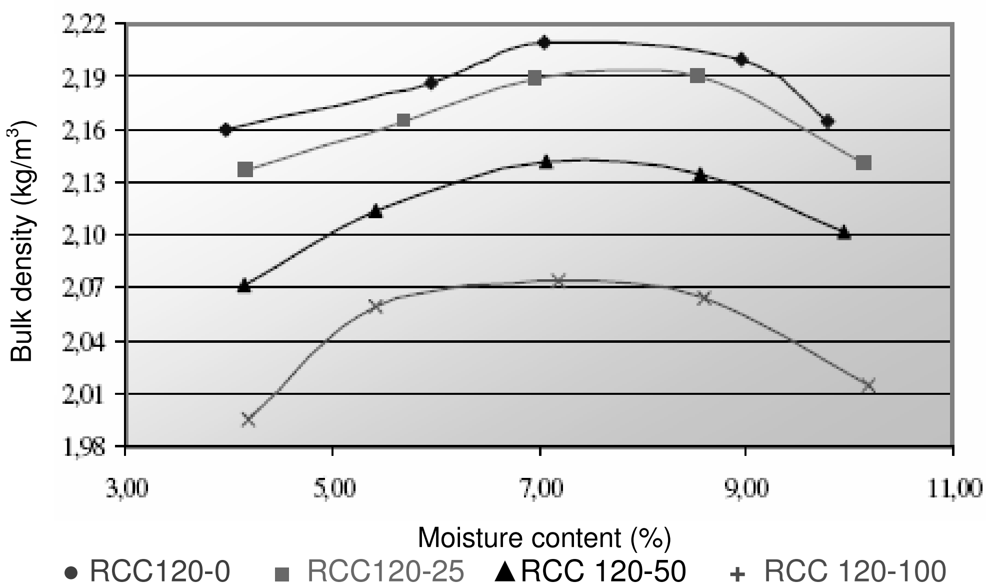

Figure 7: Compaction curves for mixtures with Cc 120 kg/m^3.

For each RCC mixture (each cement content at each level sand replacement by bottom ash) several 15x30cm cylinder were cast in order to evaluate compressive strength of mixtures at 28 days.

Figure 8 shows the development of compressive strength at 28 days (R_{28}) with Cement content and bottom ash replacing for every mixture studied.

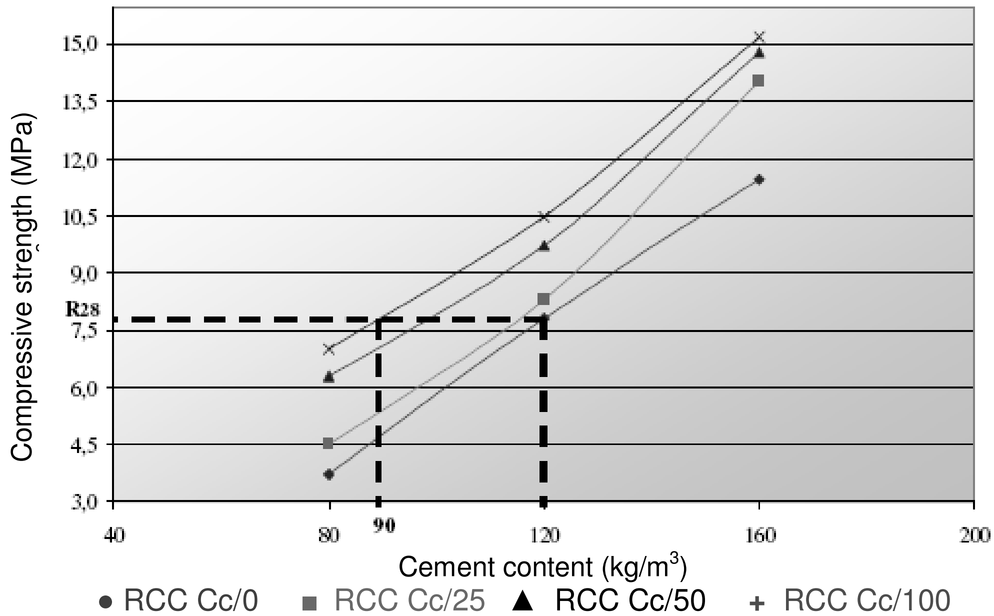

Figure 8: Development of compressive strength at 28 days (R_{28}) with Cement content and bottom ash replacing.

The modulus elasticity for mixes with total sand replacement by bottom ash and with no replacement at all was also evaluated at 28 days from 15x30cm cylinders. The results are presented on Figure 9. Brazilian standards were followed for making.

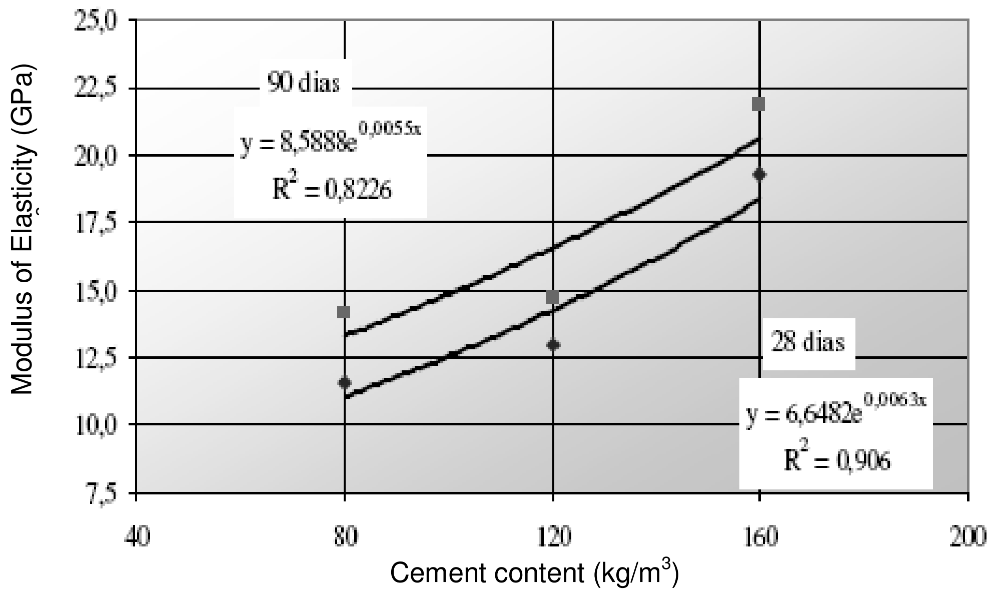

Figure 9: Development of modulus of elasticity with cement content and for total (100%) bottom ash replacing. ● 28 days ■ 90 days.

Several 15x15x50cm prismatic specimens were also for flexural strength testing cast. Adequate compacting was achieved with two layers. Figure 10 shows the procedure for compaction prismatic specimens. After the first day, all specimens were transported to a curing chamber until testing.

Figure 10: Procedure for compacting prismatic specimens.

Flexural strength was obtained at 28 and 90 days for each mixture. For the reference mixtures, with no ash, three prisms were also tested at 3 and 7 days. Brazilian standards were followed for making and testing all specimens. The results are presented in Table 4, and are graphically displayed in Figure 11.

Table 4: Flexural strength results (MPa).

Age (days)	mixture					
	RCC 80-0	RCC 80-100	RCC 120-0	RCC 120-100	RCC 160-0	RCC 160-50
3	0.12	-	0.67	-	-	-
7	0.36	-	0.82	-	1.22	-
28	0.88	0.83	1.85	2.08	2.12	1.79
90	0.91	1.22	2.34	2.70	2.58	3.82

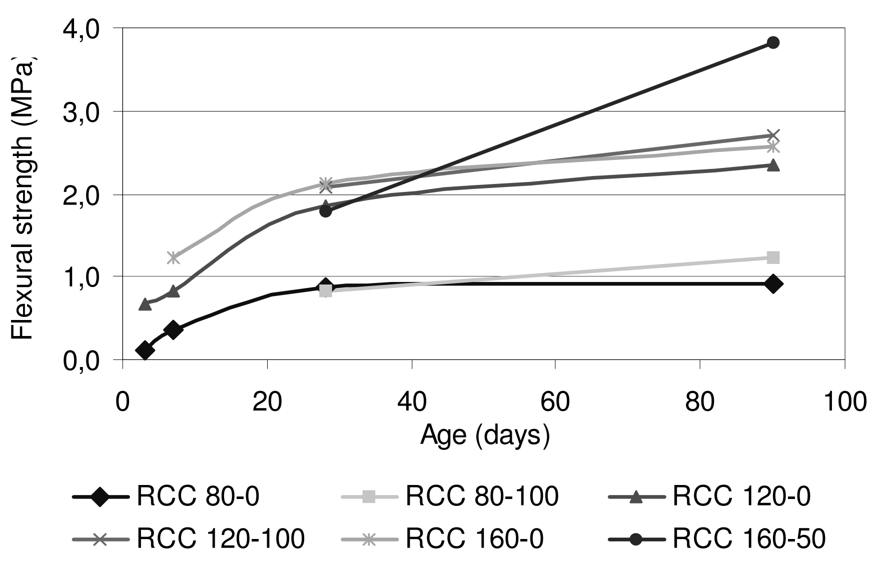

Figure 11: Development of flexural strength with time.

3. DISCUSSION

The experimental results presented in Table 4 show an increase in flexural strength with increasing amount of natural sand replacement by bottom ash. At 90 days, the mixture RCC 120-100 (with full replacement) had an increase of 15% as compared to mixture RCC 120-0, with no replacement of sand by bottom ash. For the mixture with cement content of 160 kg/m^3, such an increase was more pronounced, being on the order of 48% with 50% of sand replaced by bottom ash. The relationship between flexural strength with natural sand replacement levels by bottom ash at the three levels of cement content can be seen in Figure 12.

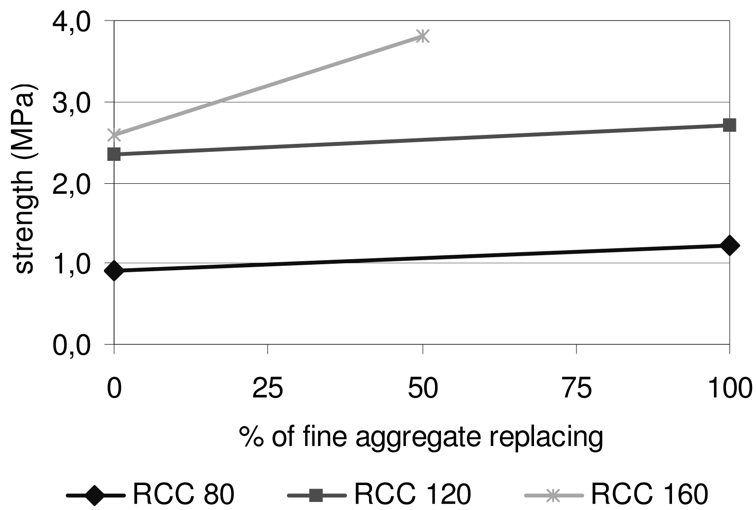

Figure 12: Relationship between sand replacement levels and flexural strength at 90 days.

The observed increase in strength at increased levels of sand replacement by bottom ash might have been caused by the tree probable factors: a better aggregate arrangement in the mixtures with bottom ash, the occurrence of some pozzolanic activity and a smooth diminution in maximum moisture content. The composite gradation curves for the mixtures shown in Figure 5 indicates that once fine sand was replaced by bottom ash, there was an increase in the material between sieves #2,38mm e #0,15mm, which may have led to a better aggregate arrangement enhancing the strength of the material. A previous study on the pozzolanic activity of this bottom ash showed some pozzolanic activity at later ages with this ash being classified as an ASTM Class F ash (Cheriaf et al., 1999).

The observed increase in flexural strength at higher levels of sand replacement by bottom ash may lead to economical benefits when incorporating such a secondary material in a RCC mixture. Figure 13 illustrates this issue. Considering that a RCC mixture was designed to obtain flexural strength of 2.5MPa at 90 days, this strength level could be obtained with a normal mixture with a cement content of around 130 kg/m^3. This level of strength could also be obtained with a mixture with bottom ash replacing 100% of the fine aggregate content and with a lower cement content of approximately 117 kg/m^3. There is a consequently decrease of the order 15% of the cement content. The mixture with bottom ash and lower cement content, besides being a potential environmental friendly mixture, also is a more economical mixture, leading to cost savings.

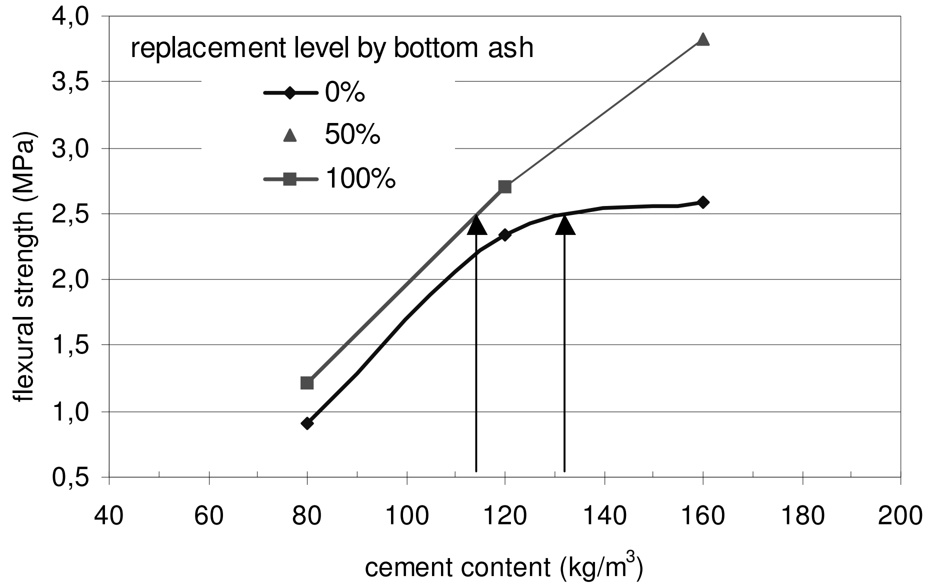

Figure 13: Relationship between cement content and flexural strength at 90 days.

4. CONCLUSIONS

- Flexural strength levels of the RCC mixtures investigated here increased as natural sand was replaced by bottom ash. At 90 days, increases of the order of 15% to 48% were observed depending on the cement content and level of natural sand replacement by bottom ash.
- For the mixtures studied here, 15% less cement could be used to achieve a flexural strength of 2.5 MPa at 90 days, when the natural fine aggregate was replaced by bottom ash.
- The obtained results indicate the feasibility of applying coal bottom ash to RCC mixtures to be used in the base coarse for composite pavements applications.

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