A FEASIBILITY STUDY OF INCORPORATING BOTTOM ASH IN ROLLER COMPACTED CONCRETE PAVEMENTS

G. Trichês, R. C. A. Pinto, and A. J. Silva
Departamento de Engenharia Civil, Universidade Federal de Santa Catarina, Florianópolis, Brazil
ecv1gtri@ecv.ufsc.br; rpinto@ecv.ufsc.br; ajs_silva@yahoo.com.br

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. 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. Flexural strength was evaluated for each mixture at 28 and 90 days. Ultrasound measurements were also performed using the indirect transmission mode to assess the relationship between p-wave speed and flexural strength. 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.

KEY WORDS

ROLLER COMPACTED CONCRETE / BOTTOM ASH / ULTRASOUND MEASUREMENTS / BASE COURSE.

1. INTRODUCTION

Roller compacted concrete (RCC) was first used as a pavement material in 1930 in Sweden; since then, several examples of succesful 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 (RCC) 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 pavement engineering, one possible application of bottom ash would be in RCC base course mixtures. Bottom ash could be incorporated replacing the fine aggregate content. 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 (Trichês et al., 2006). This material, however, must be durable and safe against leaching. Current research in Brazil, in the utilization of bottom ash in concrete bricks indicates that there is a great potential of using bottom ash in building materials.

In field applications, it is often required to monitor flexural strength with time, in order to ensure that strength design requirements are met. Such evaluation can be performed by means of concrete specimens tested on site, which, however, may require transporting special equipment to the site. Alternatively, non-destructive test methods, such as ultrasound may be used. In such case, there is no need to test concrete specimens on site. Strength development is evaluated indirectly through a previously developed relationship between concrete strength and ultrasound pulse velocity (also called p-wave velocity). There have been several examples of utilization of non-destructive test methods to concrete pavements in fast-track applications (FHWA, 1994; Whiting et al., 1994).

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, and ultrasound measurements were performed at various ages with the relationship between p-wave speed and the mechanical property evaluated for each mixture. Ultrasound waves were applied through the indirect transmission mode over the specimen surface, in order to replicate possible field applications.

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.

As far as ultrasound measurements are concerned, unique relationships between p-wave speed and flexural strength were observed for each mixture, indicating that ultrasound may be a useful tool to monitor the development of RCC properties over time on field applications.

2. EXPERIMENTAL METHODS

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:

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

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);
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 chemical composition of the coal bottom ash is presented in Table 1.

Table 1 - 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 1. 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 total sand content for mixtures with cement content of 80 and 120 kg/m^3 (RCC 80-100, and RCC 120-100), and half of the total sand content for mixture with cement content of 160 kg/m^3 (RCC 160-50). Aggregate composite gradation curves for all mixtures are presented in Figure 2. Figure 2 also shows the maximum densification gradation as given by the Fuller method with n = 0.45, and maximum aggregate size of 25.4 mm.

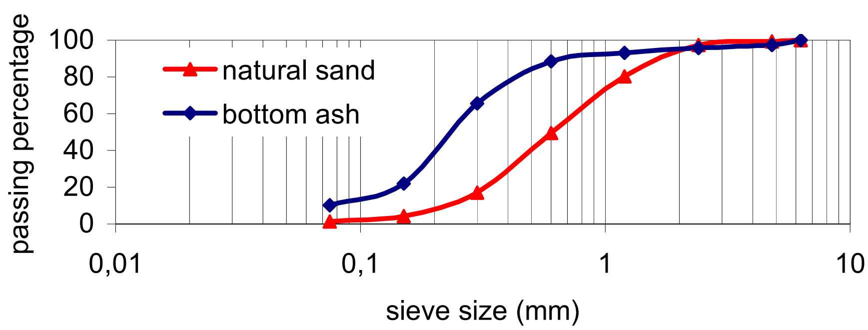

Figure 1 - Gradation curves for fine natural sand and bottom ash

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. Several 15 x 15 x 50 prismatic specimens were cast. Adequate compaction was achieved with two layers. After the first day, all specimens were transported to a curing chamber until testing.

Flexural strength was obtained from three 15x15x50 cm prisms tested 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 breaking specimens. The results are presented in Table 2, and are graphically displayed in Figure 3.

Ultrasound measurements were also performed at the prismatic specimens at 3, 7, 14, 21, 28, 56 and 90 days. Ultrasound waves were applied through the indirect transmission mode, with 54 kHz cylindrical transducers placed on the surface of the specimens. The location of the transmitting transducer was fixed at 10 cm from the side of the specimen, with the position of the receiver transducer changing in 10 cm increments. Three time travel readings were performed with transducers at 10, 20, and 30 cm apart. Table 3 presents the results obtained which are also graphically shown in Figure 4.

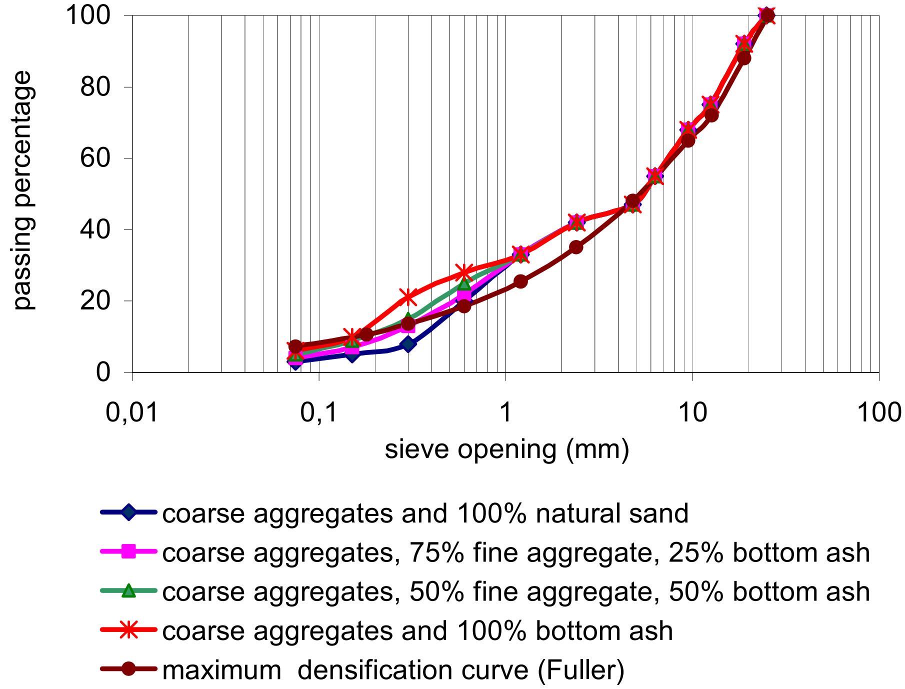

Figure 2 - Gradation curves for composite aggregates

Table 2 – 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

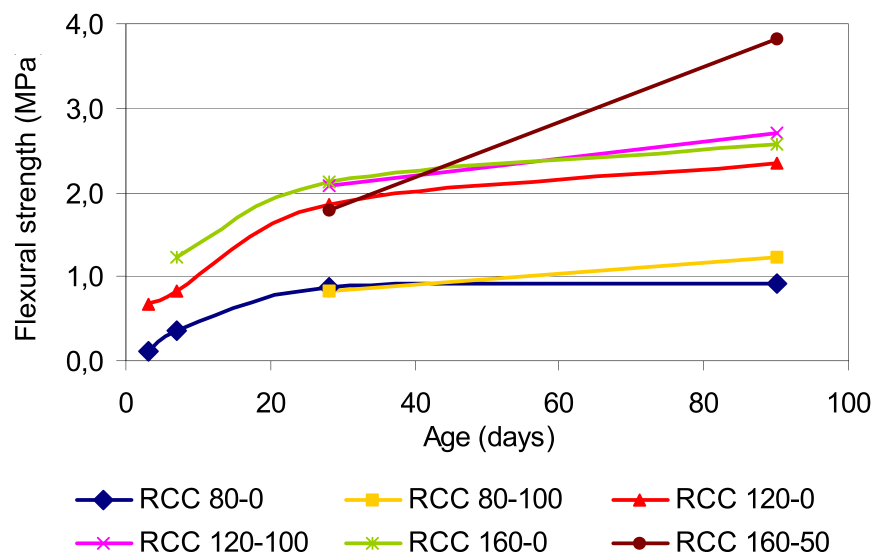

Figure 4 - Development of flexural strength with time

Table 3 - Ultrasound pulse velocities (m/s)

Age (days)	mixture					
	RCC 80-0	RCC 80-100	RCC 120-0	RCC 120-100	RCC 160-0	RCC 160-50
3	1788	1341	3282	2738	3698	2857
7	2320	2376	3728	2905	3644	3420
14	3055	2976	3892	3506	3741	3793
21	3170	3094	3977	3671	3901	3870
28	3220	3155	4096	3660	3984	3979
56	3498	3245	4194	3963	4146	4217
90	3637	3343	4306	4036	4234	4299

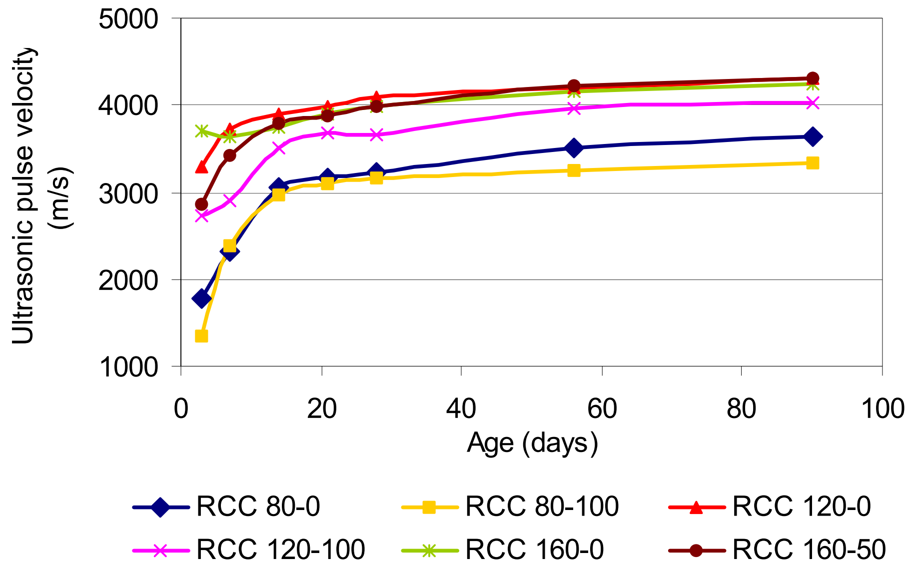

Figure 4 - Development of ultrasound pulse velocity with time

3. DISCUSSION

The experimental results presented in Table 2 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 5.

The observed increase in strength at increased levels of sand replacement by bottom ash might have been caused by two probable factors: a better aggregate arrangement in the mixtures with bottom ash, and the occurrence of some pozzolanic activity. The composite gradation curves for the mixtures shown in Figure 2, 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).

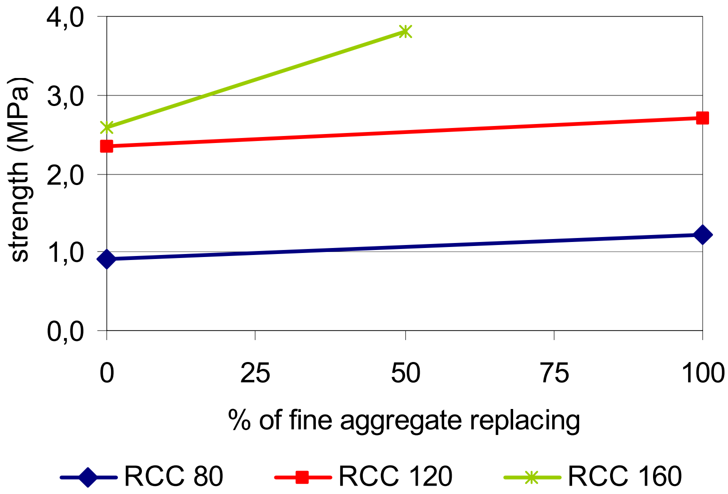

Figure 5 – Relationship between sand replacement levels and flexural strength at 90 days

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 6 illustrates this issue. Considering that a RCC mixture was designed to obtain flexural strength of 2.5 MPa 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 115 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.

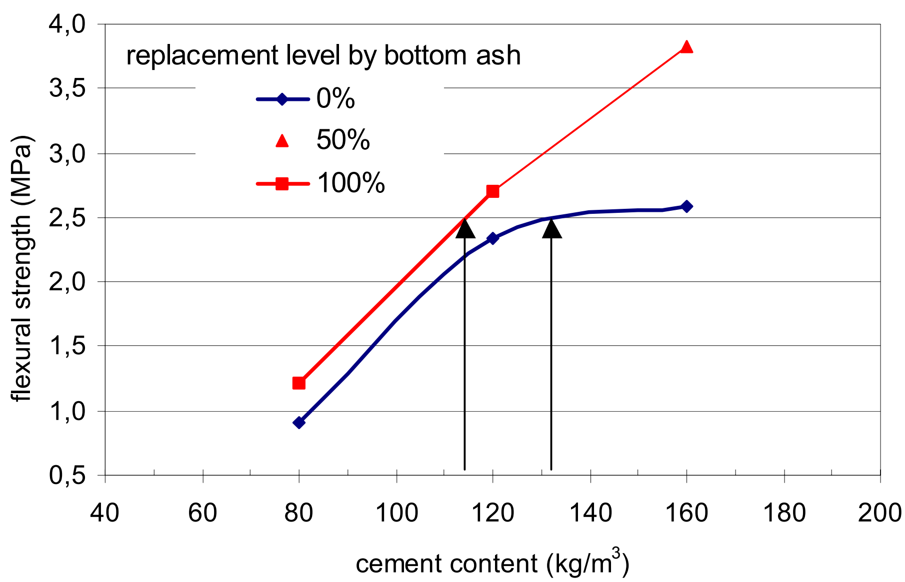

Figure 6 – Relationship between cement content and flexural strength at 90 days

Ultrasound velocities increased with time for all mixtures, as it can be seen in Table 3. For mixtures with same cement content, replacement of natural sand by bottom ash led to smaller ultrasound pulse velocities at all ages, as shown in Figure 4. The ultrasound pulse velocity is inversely related to the density of the material (Malhotra & Carino, 1991). Therefore, by replacing fine natural sand by a lower density material, such as bottom ash, the mixture bulk density decreases, explaining the decrease in the observed ultrasound pulse velocity.

Ultrasound measurements may be a helpful tool on site to estimate the development of mechanical properties of RCC with time. As such, the relationship between observed ultrasound velocities and obtained flexural strengths for the mixtures without bottom ash are presented in Figure 6.

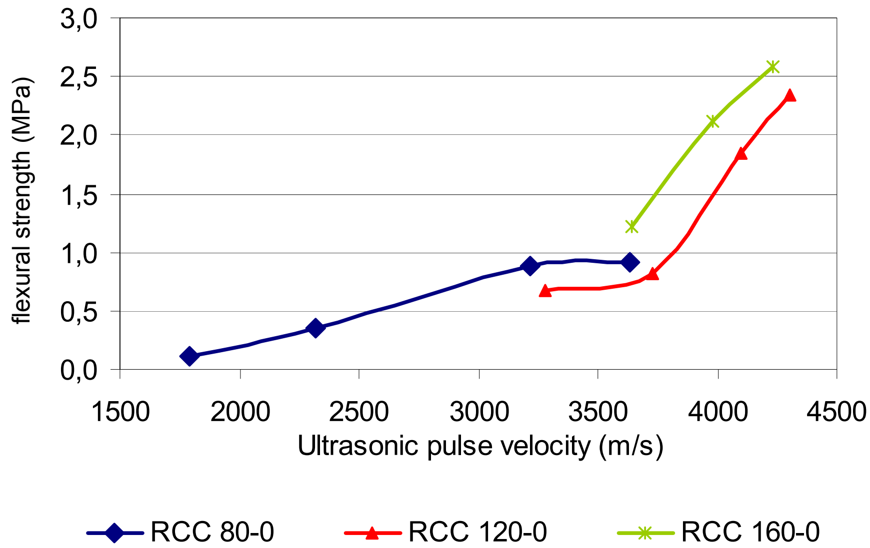

Figure 6 - Relationship between ultrasound pulse velocity and flexural strength

It can be observed from Figure 6 that it is possible to previously define a relationship between p-wave speed and flexural strength of RCC mixtures to be used on field applications through the indirect transmission mode. If the mixtures investigated here were to be applied on site, it would be necessary to use the relationships presented in Figure 6. Quality control of RCC pavements could, then, be performed with ultrasound measurements with time on the RCC pavement, which would indicate the level of strength achieved.

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.

- Unique relationships between ultrasound pulse velocities through the indirect mode of transmission and flexural strengths were obtained for the mixtures studied.

- 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.

5. ACKNOWLEDGEMENT

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