REPLACING THE AGGREGATE BY RICE HUSK ASH IN ROLLER COMPACTED CONCRETE FOR COMPOSITE PAVEMENTS

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ABSTRACT

World rice production reaches 662 million tons per year. The husks represent 20% of this amount and when burned, 20% of this byproduct is transformed into rice husk ash (RHA). In general, there is not an environmental management policy concerning this residue. Roller compacted concrete (RCC) is a material which permits the incorporation of industry byproducts such as RHA. This article presents laboratory results of mixtures of RCC with the addition of RHA in its application in composite pavements. Natural RHA was utilized in order to partially substitute the mineral aggregate in diverse proportions within the RCC dosage. The properties evaluated were compressive strength, flexural strength, and modulus of elasticity. The results demonstrated that a significant improvement in the properties studied may be achieved with the addition of RHA in RCC. This study also indicates that the addition of RHA in mixtures of RCC may lead to reduced consumption of cements and lesser demand for aggregate minerals. As such, the use of this material in highway construction in rice-producing regions would contribute to environmental management of this residue.

KEY WORDS: roller compacted concrete, rice husk ash, compressive strength, flexural strength, modulus of elasticity, composite pavement.

1 INTRODUCTION

Rice husk ash (RHA) is an agricultural waste originated from the combustion of the rice husk intended to produce energy for rice drying ovens. This ash is rich in silicon. Each ton of rice produces approximately 200 kg of husk, which when burned gives way to 40 kg of RHA (Mehta, 1992).

662 million tons of rice are produced globally every year. (FAO, 2008). The husks represent 20% of this weight, which means that 132.4 million tons of wastes are generated annually. If totally burned, an annual environmental impact of 26.48 million tons results. As there are few industrial scale applications directed towards managing RHA, a large part is used as agricultural compost or simply disposed on riverbanks, causing organic pollution.

One of the areas which has received intense research is the industrial use of RHA is the portland cement concrete technology.

The principle effects of RHA in concrete are the following:

- Chemical effect: It is associated to the reactive capacity with calcium hydroxide – $Ca(OH)_2$ – formed during the hydration of portland cement, in order to form additional calcium hydrate silicate C-S-H, which is the principle product responsible for strength of the hydrated cement pastes.

- Physical effect: The principle physical effects which may be generated by the RHAs are the following:

  - Mircrofiller effect: It is characterized by an increase in specific mass of the resulting mixture through filling the gaps with miniscule RHA particles, whose average diameter must be similar or less than the average diameter of the cement particles;

- Refining the pores structure and the cement hydration products; caused by the little RHA particles which may act as nucleation points for hydration products. As such, the growth of C-S-H crystals will occur not only on the surface of the cement grains, but also in the pores occupied by the addition and the water (RHA restricts the spaces in which the hydration products may grow, generating a great number of little crystals instead of few larger-sized crystals); and

- Alterating the microstructure of the transition zone between the paste and the aggregate: placement of finely divided RHA interferes in the movement of water molecules to the solids of the mixture, reducing or eliminating the accumulation of free water which normally remains under the aggregates. Beyond this, it diminishes the width of the transition zone through filling existing gaps near the surface of the aggregate (mircrofiller effect); interferes in the crystal growth, restricting their size and reducing the degree of calcium hydroxide crystal orientation together with the aggregate (addition particles acting as nucleation points); and reduces $Ca(OH)_{2.}$concentration. All these effects significantly improve the transition zone between the paste and the aggregate, reflecting a performance increase for the concrete from a mechanical and durability perspective.

Roller compacted concrete (RCC) is a “dry” mixture of aggregates, water, and cementing materials compacted by vibratory compactors or compacting equipment (ACI Committee, 1995). RCC became known on a worldwide level with the petroleum crises in the 1970s, which significantly increased the costs of asphalt pavement (Pittmann, 1989; Gomez, 1987).

RCC may be produced with any types of aggregates used in normal concrete production, as long as they fulfill specific grades. In the same manner, any type of cement may be used in RCC production. The cement contents to elaborate base and sub-base layers of pavements may vary from 80 kg/m^3 to 200 kg/m^3. The water content may vary between 4% and 7% of the total dry mass (Pitta & Hurtado Diaz, 1991).

RCC is a material which permits the incorporation of industrial byproducts. In RCC, these residues may be directly added to the mixture in diverse proportions, or to substitute a part of the aggregate mineral. In the latter case, environmental benefits are achieved not only in using residual material but in lesser demand for aggregate minerals.

Composite pavements are structures which combine flexible and rigid materials, aiming to increase highway durability. According to the World Road Association (PIARC - Permanent International Association of Road Congresses), there are 3 types of composite pavements: Type 1 is pavement conformed to a rigid structure (cementitious or Roller Compacted Concrete layer) covered with a layer of asphaltic mixture; Type 2 is pavement conformed to a rigid structure covered by pre-molded elements; and Type 3 is pavement conformed to a flexible structure covered by a rigid layer (whitetopping).

The great advantage to Type 1 pavement is allied to the strength provided by the cementitious layer to comfort with the role provided by the asphalt mixture. Beyond which, the structure of asphalt coating will work the lower levels of tensile deformation due to minor deformation of the cementitious layer, thus increasing the durability as well as resistance against fatigue cracking.

In this article, we analyze the influence of RCC additions as aggregate mineral substitutes in dosing the RCC. Our objective is to apply it to Type 1 composite pavements.

In the first stage, the influence of adding different proportions of RHA in compressive strength was analyzed at 28 days in RHA mixtures containing 120 kg/m^3 of cement, utilizing a mixture without RHA as a reference. After analyzing the results, the 5% mixture of RHA was selected as that which offered the best results in terms of compressive strength.

In the second stage of the study, the influence of adding 5% RHA in the RCC in mixtures containing different cement contents was analyzed. The RCC mixtures were prepared containing 80, 120, and 160 kg/m^3 of cement. The results obtained were compared with those obtained with the mixtures without RHA. The mechanical properties studied were compressive strength at 7, 14, 28, and 90 days, a flexural tensile strength at 28 and 90 days, and a modulus of elasticity at 28 days.

In the third stage of the study, a composite pavement structure was designed, in which a RCC base with the addition of RHA was used. This structure was compared to the flexible pavement structure.

2 METHODOLOGY

2.1 Materials

The cement utilized in this study was Brazilian CP II Z 32 cement, which has a density of 2.99 kg/dm^3 and a specific Blaine area of 370m^2/kg. The RCC is made in the southern part of the state of Santa Catarina, Brazil, and was collected in rice husk drying ovens without temperature control. The chemical characteristics of the cement and the RHA are shown in Table 1. Figure 1 presents the X-Ray pattern of RHA.

Table 1 – Chemical characteristics of the cement and the rice husk ash.

	CaO (%)	SiO_2 (%)	Al_2O_3 (%)	MgO (%)	Fe_2O_3 (%)	SO_3 (%)	K_2O (%)	Loss on ignition (%)
Cement	54.60	20.87	5.96	5.89	3.20	3.03	1.01	5.06
RHA	0.26	62.96	22.73	0.01	0.21	0.04	0.45	12.76

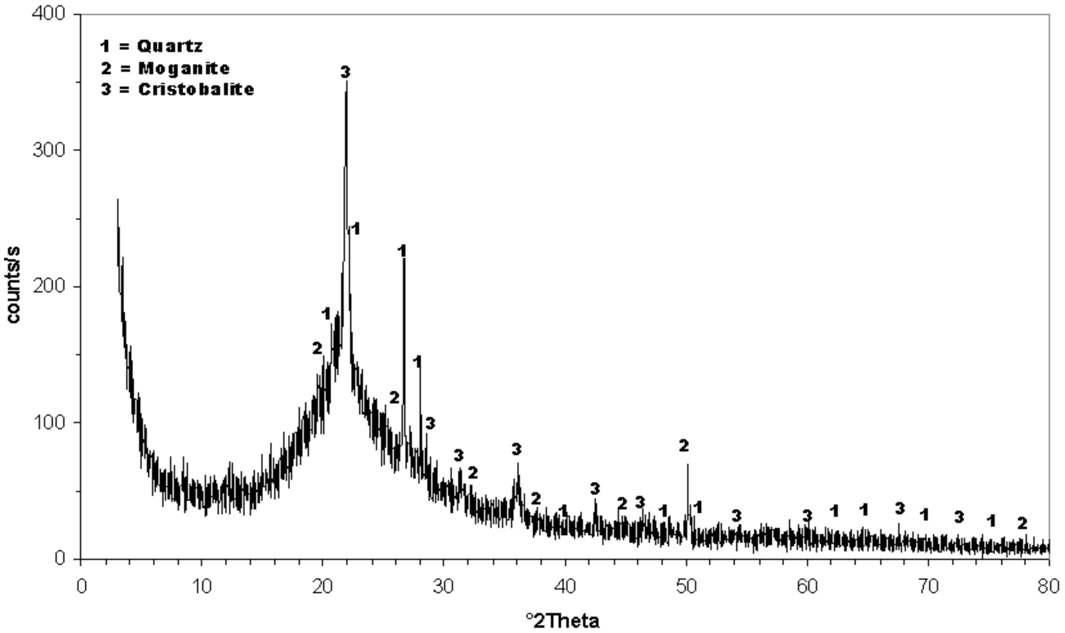

Figure 1 – Rice husk ash X-Rays Difratogram.

The mineral aggregates used are of granular origin. Table 2 shows the physical characteristics of the aggregates and the RHA.

Table 2 – Gradation and density of the aggregates and the rice husk ash.

Sieve		Coarse aggregates			RHA
#	(mm)	38 mm	19 mm	9,5 mm	
1 ½”	38	100	-	-	-
1”	25	85.99	-	-	-
¾”	19	57.88	100	-	-
½”	12.5	24.18	83.59	-	-
3/8”	9.5	16.21	47.53	100	-
¼”	6.3	10.56	11.55	94.14	-
# 4	4.8	7.22	6.96	81.75	-
# 8	2.4	4.36	4.66	58.63	-
# 16	1.2	3.28	3.32	43.04	100
# 30	0.6	2.61	2.29	28.59	98.79
# 50	0.3	2.12	1.65	18.72	92.43
# 100	0.15	1.70	1.24	12.37	79.70
# 200	0.075	1.34	0.91	8.24	66.39
# 230	0.063	-	-	-	64.74
# 270	0.053	-	-	-	62.31
# 325	0.044	-	-	-	59.07
# 400	0.037	-	-	-	55.74
Density (kg/dm^3)		2.64	2.63	2.63	2.21

2.2 RCC mix

The method utilized for the RHA dosage is derived from the soil compaction, and is based on the ratio between the apparent dry specific density of the dry mixture and the RHA moisture. The compacting energy employed was the Intermediate Proctor (1.27 Joules/cm). Optimum moisture represents the greatest specific density obtained for this energy.

With the optimum moisture value, test bodies were molded to evaluate the mechanical properties of the RCC. For the compressive strength test, 15x30cm cylindrical test bodies were molded and tested at 7, 14, 28, and 90 days. For the flexural tensile strength test, 15x15x50cm prism-shaped test bodies were molded and tested at 28 and 90 days. Finally, for the modulus of elasticity test, 15x30cm cylindrical test bodies were molded and tested at 28 days.

The cylindrical test bodies were molded in 5 layers, applying 65 socket compactor blows per layer. The prism test bodies were molded in 2 layers, applying 345 blows per layer. The test bodies were cured in a wet chamber with a relative humidity of 95% at 23°C.

The following RCC mixtures were studied:

Mixtures without adding RHA.
- M 0/80 : RCC Mixture with 0% RHA addition and 80 kg/m^3 of cement;
- M 0/120 : RCC Mixture with 0% RHA addition and 120 kg/m^3 of cement; and
- M 0/160 : RCC Mixture with 0% RHA addition and 160 kg/m^3 of cement.

Mixtures with rice husk ash additions.
- M 5/80 : RCC Mixture with 5% RHA replacing the aggregate and 80 kg/m^3 of cement;
- M 3/120 : RCC Mixture with 3% RHA replacing the aggregate and 120 kg/m^3 of cement;
- M 5/120 : RCC Mixture with 5% RHA replacing the aggregate and 120 kg/m^3 of cement;
- M 7/120 : RCC Mixture with 7% RHA replacing the aggregate and 120 kg/m^3 of cement;
- M 10/120 : RCC Mixture with 10% RHA replacing the aggregate and 120 kg/m^3 of cement; and
- M 5/160 : RCC Mixture with 5% RHA replacing the aggregate and 160 kg/m^3 of cement.

The proportions of materials utilized in elaborating the RCC mixtures are shown in Table 3.

Table 3 – Proportions of dry materials (kg/m^3) of the RCC mixtures

Mixture	Cement	Coarse aggregate			RHA
		38 mm	19 mm	9,5 mm	
M 0/80	80	824.8	206.4	1031.2	-
M 0/120	120	810.0	202.8	1012.8	-
M 0/160	160	795.2	198.4	995.2	-
M 5/80*	80	868.0	181.6	868.0	100.93
M 3/120	120	876.0	178.8	876.0	60.97
M 5/120	120	852.0	178.8	852.0	99.09
M 7/120	120	831.6	177.6	831.6	135.64
M 10/120	120	807.6	157.2	807.6	186.57
M 5/160	160	835.2	174.4	835.2	97.09

* For example, the mixture 5/80 is composed by: 80 kg/m^3 of cement; 5% (100.93 kg/m^3) of RHA replacing the aggregate; and 95% of aggregate (1917,6 kg/m^3).

3 RESULTS AND ANALYSIS

3.1 Optimum moisture and maximum dry apparent specific density in RCC mixtures

Table 4 shows the results of optimum moisture and maximum dry apparent specific density in the studied mixtures.

Table 4 – Optimum moisture and maximum density of the RCC mixtures.

Mixture	Optimum moisture (%)	Maximum Density (kg/dm^3)
M 0/80	6.04	2.25
M 0/120	6.11	2.27
M 0/160	6.17	2.27
M 5/80	6.35	2.19
M 3/120	6.24	2.26
M 5/120	6.75	2.20
M 7/120	7.26	2.15
M 10/120	7.96	2.11
M 5/160	7.25	2.21

3.2 Compressive strength

The compressive strength test was carried out according to the ASTM Norm C39/C39M. Table 5 shows the compressive strength values at 28 days for the RCC mixtures containing 120 kg/m^3 of cement and RHA percentages varying between 0, 3, 5, 7, and 10%. Figure 2 shows the influence of RHA addition percentages on compressive strengths to the RCC mixtures containing 120 kg/m^3 of cement.

Table 5 – Compressive strength of the RCC mixtures with varying percentages of RHA at 28 days.

Mixture	Compressive strength (MPa)
M 0/120	7.95
M 3/120	12.62
M 5/120	14.16
M 7/120	13.85
M 10/120	8.70

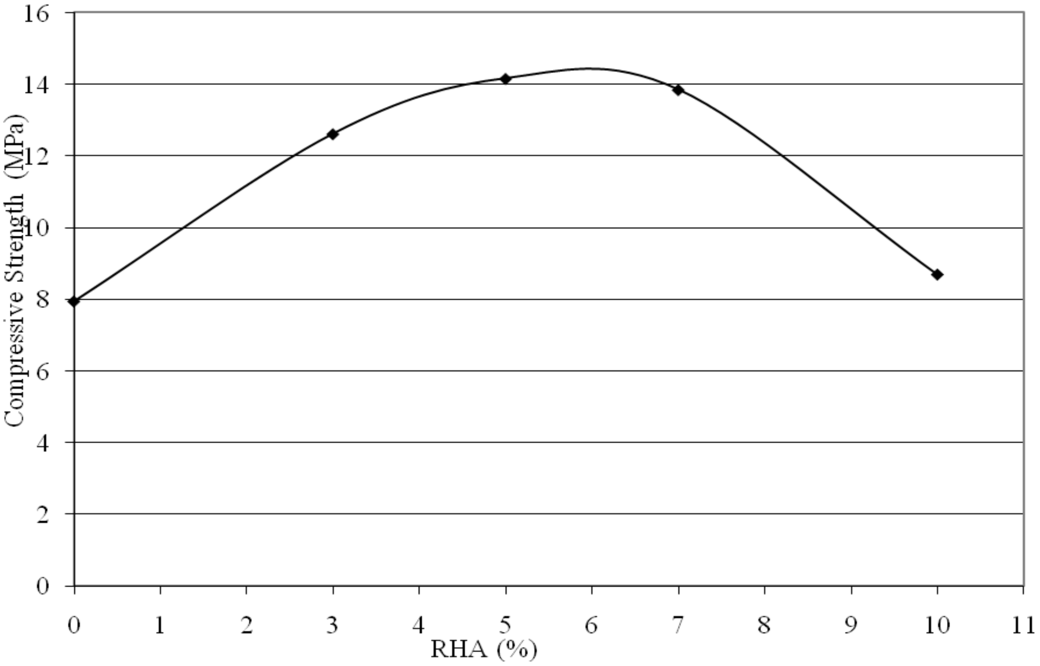

Figure 2 – Influence of the percentage of RHA addition to compressive strength of the RCC at 28 days.

In Table 5 and in Figure 2, one can observe tha the greatest compressive strength value of the RCC mixtures containing 120 kg/m^3 of cement is attained when one adds 5% of RHA. This percentage was thus chosen in order to elaborate the RCC mixtures of the second stage of this study.

Table 6 shows the compressive strength results for the RCC mixtures with 0 and 5% RHA and cement consumptions of 80, 120, and 160 kg/m^3. Figure 3 shows the influence of cement consumption on compressive strength for the RCC mixtures at 28 days.

Table 6 – Compressive strength (MPa) of the RCC mixtures with 0 and 5% RHA additions.

Mixture	Age (days)			
	7	14	28	90
M 0/80	3.48	4.07	5.02	5.84
M 0/120	6.08	7.16	7.95	8.97
M 0/160	10.47	11.78	12.31	14.73
M 5/80	6.39	7.44	9.42	13.71
M 5/120	10.42	12.34	14.16	17.40
M 5/160	13.26	15.25	17.05	21.00

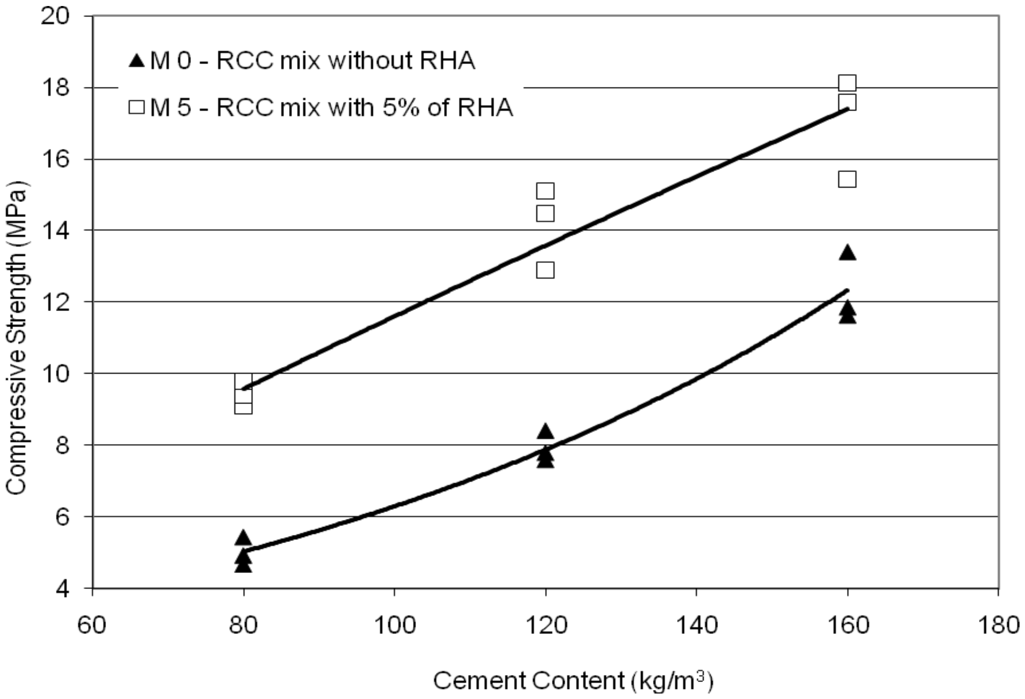

Figure 3 – Influence of cement consumption on compressive strength of the RCC mixtures at 28 days.

3.3 Modulus of elasticity

The test for modulus of elasticity was carried out according to the ASTM Norm C469 and determined at 28 days. Table 7 shows the elasticity values for the RCC mixtures. Figure 4 shows the influence of cement consumption on the modulus of elasticity for the RCC mixtures at 28 days.

Table 7 – Modulus of elasticity (GPa) of the RCC mixtures.

Mixture	Modulus of elasticity (GPa)
M 0/80	6.24
M 0/120	14.61
M 0/160	16.77
M 5/80	10.75
M 5/120	17.47
M 5/160	19.76

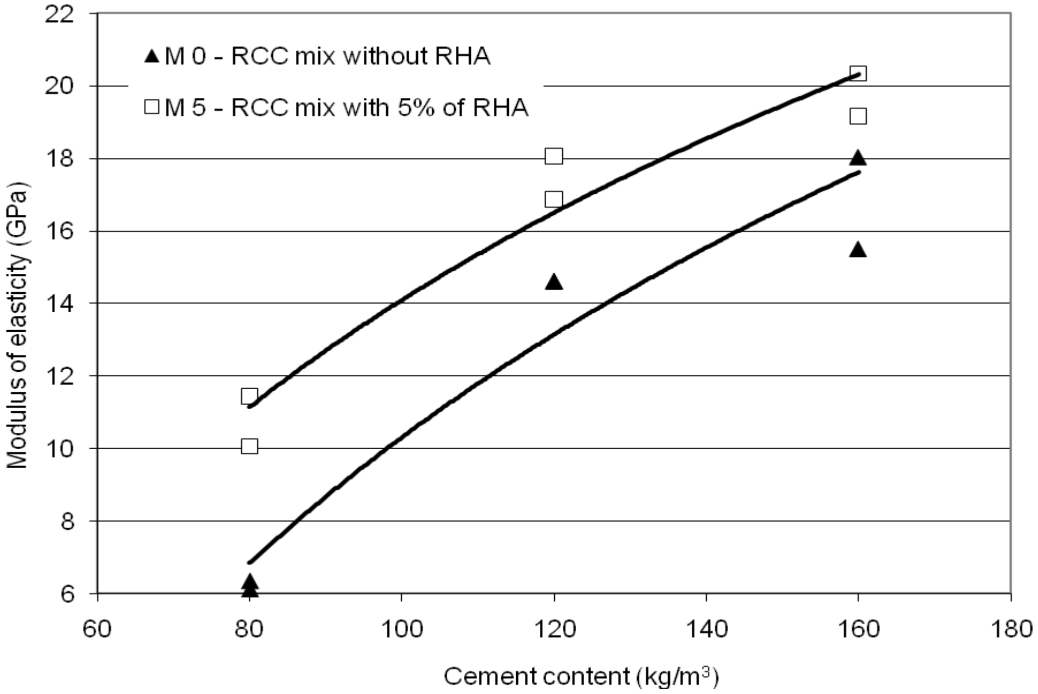

Figure 4 – Influence of cement consumption on the modulus of elasticity of the RCC mixtures at 28 days.

3.4 Flexural strength was carried out according to Norm ASTM C78, at 28 and 90 days. Table 8 shows the flexural tensile strength of the RCC mixtures. Figure 5 shows the influence of cement consumption on flexural tensile strength in the RCC mixtures at 28 days.

Table 8 – Flexural strength (MPa) of the RCC mixtures.

Mixture	Age (days)	
	28	90
M 0/80	1.12	1.19
M 0/120	1.81	1.90
M 0/160	2.53	2.72
M 5/80	1.59	1.97
M 5/120	2.54	2.92
M 5/160	2.96	4.09

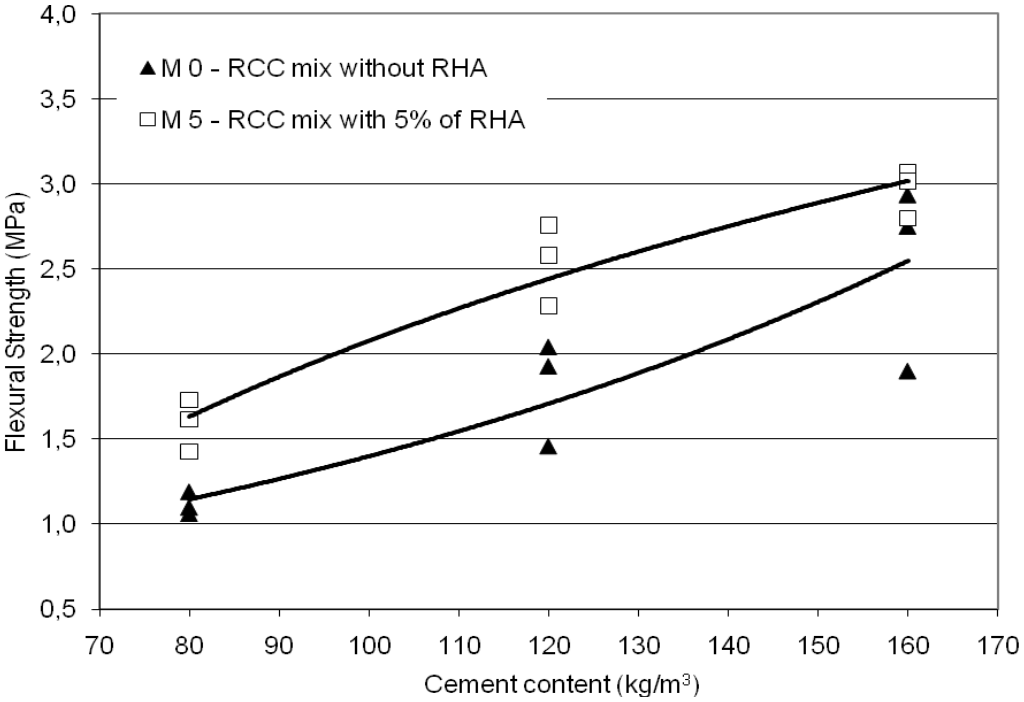

Figure 5 – Influence on cement consumption in flexural strength of the RCC mixtures at 28 days.

Figure 6 shows the cement consumption necessary to reach a flexural strength (fctm) at 2,1 MPa. One can observe that the cement consumption for the RCC mixture with 5% addition of RHA is around 40 kg (28%) less than that of the mixture without adding RHA.

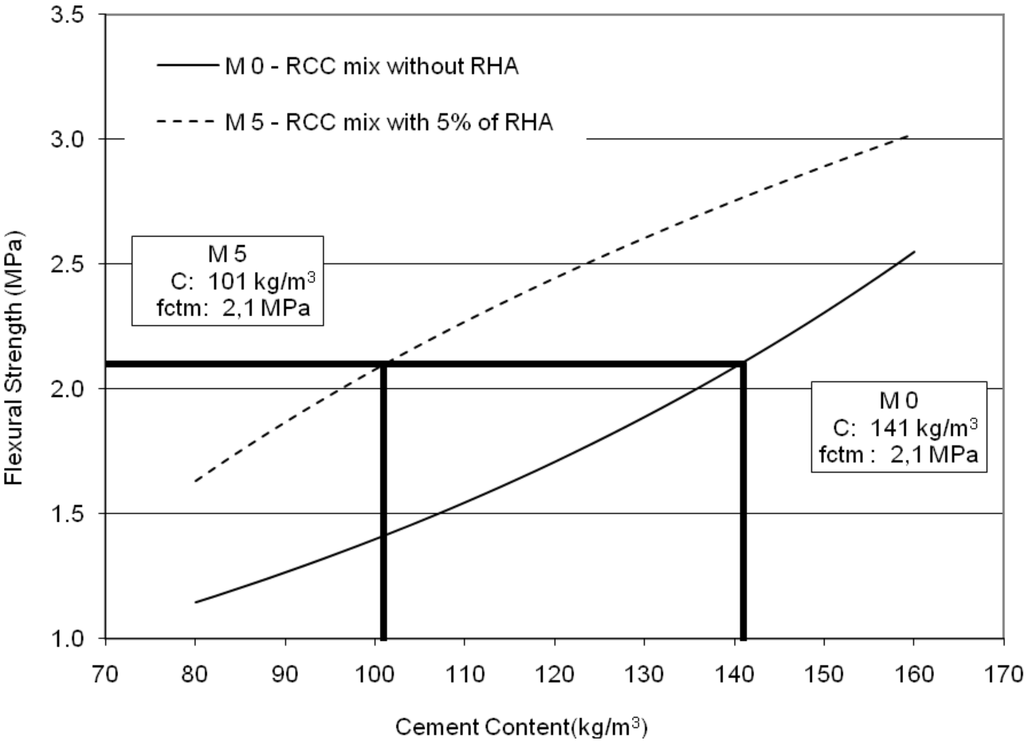

Figure 6 – Cement consumption necessary to achieve 2.1 MPa flexural resistence in the RCC mixtures at 28 days.

4 PAVEMENT DESIGN

In this stage a structure of composite pavement was structured with a RCC base and a flexible pavement structure. These structures were designed for a lifetime of Nf = $1x10^8$ equivalent standar axles of 8.2 ton, calculated with the USACE coefficients (or $3x10^7$, according to the AASHTO methodology).

The two structures were analyzed using the Elsym5 program. A simple two-wheel 8.2 ton axis load was simulated, considering two loads of 20.5 kN wheels with 0.57 MPa, separated by a distance of 31.0 centimeters. Table 9 shows the mechanical characteristics of the designed structures.

Table 9 – Mechanical characteristics of the materials of the designed structures.

Layer	Material	Poisson Ratio	Resilient Modulus (MPa)	Thickness (cm)
Flexible pavement				
Surface layer	Hot mix rubber asphalt	0.30	4500	17
Base	Granular	0.35	350	14
Sub base	Granular	0.35	200	17
Sub grade	Clay	0.45	100	-
Composite pavement				
Surface layer	Hot mix rubber asphalt	0.30	4500	4,5 *
Base	CCR M 5/100*	0.20	14070	19 *
Sub base	Granular	0.35	200	13 *
Sub grade	Clay	0.45	100	-

* Minimum execution widths for each layer.

For the base layer of the composite pavement structure, an RCC mixture with 100 kg/m^3 of cement was used with the intent to achieve a reduction in the structure's cement consumption. The modulus of elasticity value for this mixture is 14.07 GPa and the flexural tensile strength is 2.08 MPa.

The following parameters were evaluated in our analysis: deformation in the inferior surface of the coating layer (εt), traction deformation in the inferior surface of the RCC layer (σt), vertical tension on the top of the subgrade (σv), and vertical deformation on the top of the subgrade (εv). Table 10 shows the results obtained with the Elsym5 program.

Table 10 – Parameters calculated by the Elsym5 program.

Parameter	Unit	Flexible Pavement	Composite Pavement
εt	x 10^{-6} mm/mm	119	Layer working in compression
σt	MPa	-	0.812
σv	MPa	0.025	0.017
εv	x 10^{-6} mm/mm	190	110

In order to estimate the service life of the pavement – number of solicitations equal to the standard 8.2 ton axis (Nf), the following models were utilized:

- Fontes' Fatigue Model (2009) for asphalt and asphalt-rubber mixture

This fatigue model was developed for fabricated mixtures, with asphalt-rubber (binder modified through moisture with 15% ground rubber from an unusable tire added). The fatigue tests were conducted in prism test bodies submitted to 4 point alternated bending. The test temperature was 20°C and the load frequency was 10 Hz. The model was the following:

$$Nf = 2.031x10^{20} (1/ \varepsilon t)^{5,915} \qquad (1)$$

where: Nf = number of load repetitions in order to create a fatigue rupture (USACE); and,
εt = specific traction deformation found in the bottom of the asphalt layer ($x10^{-6}$).

- Trichês Model (1993) for RCC fatigue

This fatigue model was developed by RCC mixtures with cement consumptions at 120 kg/m^3. The tests were conducted in simple 4 point bending at 20°C and a 5 Hz load frequency. The model is the following.

$$Nf = 10^{(14, 911 - 15, 074 \text{ x } SR)} \qquad (2)$$

where: Nf = number of load repetitions in order to create a fatigue rupture (USACE); and,
SR = Ratio between RCC layer traction tension (σt) and the resistance to flexural traction (fctm).

- Heukelom & Klomp Model (1962)

This model defines the maximum tension a subgrade can take without suffering a shear rupture (Medina & Motta, 2005). The model is the following.

$$\sigma v = (0{,}006\ MR)/(1+0{,}7 \log Nf) \qquad (3)$$

where: σv = admissible vertical tension on the top of the subgrade, in MPa;
MR = module resilient to subgrade, in MPa; and
Nf = number of load repetitions until a shear rupture (AASHTO).

- Asphalt Institute Model

This model evaluates the maximum vertical deformation at the top of the subgrade in order to avoid that there is significant plastic deformation. The model is the following.

$$Nf = 1{,}365x10^{-9}\ \varepsilon v^{-4{,}477} \qquad (4)$$

where: Nf = number of repetitions for an excessive deformation rupture (AASHTO); and
εv = specific deformation vertical limit at the top of the subgrade.

The service life estimated by the models shown in Equations 1, 2, 3 and 4 for the two pavement structures (flexible and composite) are presented in Table 11.

Table 11 – Service life of the pavement structures.

Parameter	Model	Service life flexible pavement	Service life composite pavement
εt	Fontes	$1.07x10^8$ (USACE)	Layer working to compression
σt	Trichês	-	$1.06x10^9$ (USACE)
σv	Heukelom e Klomp	$1.00x10^{33}$ (AASHTO)	$1.00x10^{49}$ (AASHTO)
εv	Asphalt Institute	$6.24x10^7$ (AASHTO)	$7.21x10^8$ (AASHTO)

As can be observed in Table 11, the minimum construction widths for the composite pavement layers result in a structure capable of supporting greater traffic than the flexible structure designed for the $1x10^8$ traffic.

CONCLUSIONS

The optimum moisture values of the RCC mixtures with the addition of RHA (Table 4) are greater than those without RHA addition. This phenomenon is due to the porous structure of the RHA and its fineness which causes a greater demand for water from the RCC. This water does not participate in the cement hydration process, causing a reduction in the dry apparent specific density mixtures, and consequently its porosity.

The addition of 5% RHA to the RCC produces increases in the compressive strength, flexural strength, and modulus of elasticity values. These increments are independent of the curing age of the mixtures or the cement consumption utilized.

The addition of 5% RHA to the RCC causes the greatest increments in compressive strength of the 120 kg/m^3 cement consumption mixtures (Table 5).

The addition of 5% RHA in the RCC diminishes the cement consumption necessary to reach desired flexural strength (Figure 6). The addition of RHA also produces a reduction in the quantity of necessary mineral aggregates in RCC dosage (Table 3), collaborating in this manner to preserving the environment.

The design carried out with the Elsym5 program shows that the composite pavement structure is capable of achieving a greater service life than the flexible pavement structure.

Considering the previous items, the use of RCC in constructing highways in rice producing regions may contribute to environmental management of this agricultural byproduct.

Complete data from the study performed may be found in Villena (2009).

ACKNOWLEDGEMENTS

The authors would like to thank to the CNPq for the master’s scholarship of the first author, to the COOPERSULCA Ltda Cooperative for the supply of the RHA and to the contractor IVAI for the supply of the aggregates.

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