STRENGTH PROPERTIES OF ROLLER COMPACTED CONCRETE CONTAINING RICE HUSK ASH

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ABSTRACT

The amount of world rice production reaches around 662 million tons a year. The husks represent 20% of this value. By burning it, 20% of this by-product is transformed into rice husk ash (RHA). At present time, merely a small part of this material serves for further usage. So far no general policy has been developed to determine how to manage this by-product. The Roller Compacted Concrete (RCC) is a material that accepts the incorporation of industrial by-products in its composition, such as for example the RHA. This article presents a laboratorial research of RCC mixtures that were added RHA in partial substitution of the mineral aggregate and its influence in the compressive strength, flexural strength and modulus of elasticity, 3, 7, 14, 28 and 90 days after moulding. It have been investigated mixtures of RCC with cement content of 80, 120 and 160 kg/m^3 and 5% of RHA. The results reveal that best values for the mentioned properties were offered by substituting 5% of the aggregate by RHA. Regarding the compressive strength, the achieved increase exceeded 135% in comparison to the mixture without RHA. For the flexural strength this increase exceeded 60% and for the modulus of elasticity, 70%. The addition of RHA to RCC mixtures can lead to using less cement. Taking this aspect into account, it can be followed that the use of the investigated by-product of rice production in the construction of highways in rice producing region can contribute to the environmental management of the rice productions' commodity chain.

1. Introduction

Rice husk ash (RHA) is a discarded agricultural by-product, generated by the combustion of rice husk, aiming to the production of energy for ovens used to dry rice. This ash is rich in silica. Each ton of rice produces approximately 200 kg of husks, which, subsequently burned, generate 40 kg of RHA (Mehta, 1992).

Around 662 million tons of rice are annually produced on global level. (FAO, 2008). The husks represent 20% of this weight; as a consequence 132.4 million tons of rice by-product are generated every year. By burning it, 20% of this by-product is turned into RHA, which accounts for an environmental impact of 26.48 million tons. Given that there is no appropriate strategy directed towards the management of the majority of the

RHA, a considerable share of it is used as agricultural compost or just discarded at the edge of rivers. Latter practice is causing damaging organic pollution.

Roller Compacted Concrete (RCC) is a dry mixture of aggregates, water and cement, compacted by vibratory rollers or plate compaction equipment (ACI Committee 325, 1995). The use of RCC peaked in the 70's due mainly to the oil crisis, which significantly raised asphalt concrete paving costs (Pittmann, 1989; Gomez, 1987). Some countries, such as the United States, U.K., France, Spain, and Canada, began to use RCC for paving military and industrial areas, and airport surfaces. There were 30% cost savings in these projects.

RCC can be manufactured with the aggregates used in normal concretes, as long as they follow the specified gradation. Similarly, any type of cement can be used in RCC production. Cement contents may vary from 80 kg/cm^3 to 200 kg/cm^3 for base and sub-base coarse applications. Water content may vary for 4% to 7% of the total mass of dry material. RCC is very sensitive to water content variations, probably more than normal concrete. Lack of sufficient water promotes segregation in the mixture, making it harder to compact and to properly finish its surface. On the other hand, excess water also makes compaction difficult due to the higher plasticity of the mixture (Pitta and Hurtado Diaz, 1991).

Roller compacted concrete is a friendly pavement material in which to incorporate by-products from industries. The use of by-product materials in RCC can be achieved by directly adding these materials to the mixture proportions, or by replacing fine mineral aggregate content. In the latter case, benefits to the environment not only come due to the utilization of by-product materials, but also due to the lower demand for natural fine aggregates.

In this paper it was analysed the impact of adding RHA to RCC in substitution of the mineral aggregation mechanical properties of the mixture. The results were compared to those obtained for mixtures without RHA. For this purpose mixtures of RCC were dosed, containing 80,120 and 160 kg/m^3 of cement and from 0% to 5% RHA replacing the mineral aggregate. In the testing process the following properties were observed: compressive strength, flexural strength and modulus of elasticity.

2. Methodology

2.1 Materials used in the research

The cement used in this research was the Brazilian cement CP II Z 32. It features a specific mass of 2,99 kg/dm^3 and a specific area Blaine of 370 m^2/kg. The RHA derives from Southern Santa Catarina State in Brazil and was collected from ovens without temperature control. The chemical characteristics of the cement as well as of the RHA are shown in Table 1. Figure 1 displays the XRD pattern of RHA.

Table 1. Composition of the cement CP II Z 32 and RHA.

	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

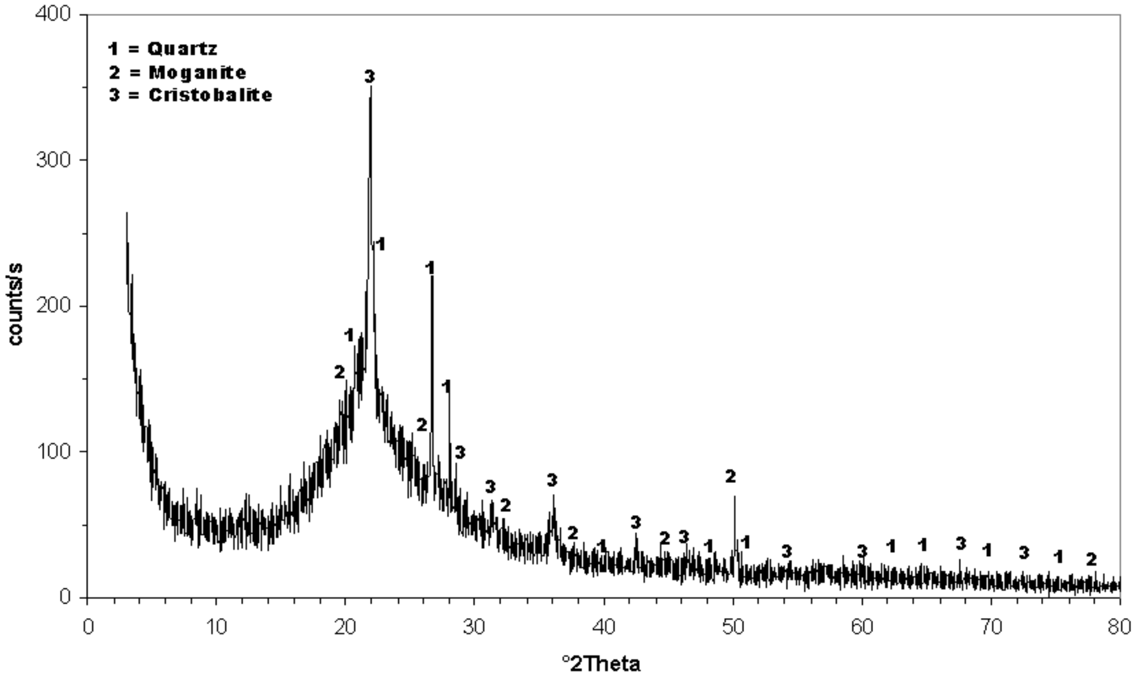

Figure 1. XRD pattern of RHA

The aggregates used in testing are taken from granite rocks. Table 2 displays the physical characteristics of the aggregates and RHA.

Table 2. Gradations and densities of aggregates and RHA.

Sieve opening		Coarse aggregate			RHA
#	(mm)	38 mm	19 mm	12,5 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 design

The method employed for design is derived from the soil compaction method, and is based on the relationship between the bulk density of the dry mixture and the moisture content of RCC.

The nomenclature of the mixtures tested is the following:
- M 0: RCC mixtures without the addition of RHA (control mixture);
- M 5: RCC mixtures with the addition of 5% of RHA added to it;
- M 80: RCC mixture with 80 kg/m^3 of cement content;
- M 120: RCC mixture with 120 kg/m^3 of cement content;
- M 160: RCC mixture with 160 kg/m^3 of cement content;
- M 0/X: RCC mixture without the addition of RHA (control mixture) with "X" content of cement; and
- M 5/X: RCC mixture with the addition of 5% of RHA added to it with "X" content of cement.

The optimum moisture content of the mixture was determined from the compaction process. The relationship between bulk density and moisture content of RCC over a range of moisture content was established with the optimum moisture content as the one corresponding to the peak of the moisture-density curve.

With the optimum moisture content, specimens were moulded to evaluate the mechanical properties of the RCC. For the compressive strength test, 15x30 cm cylindrical specimens were moulded to be evaluated 7, 14, 28 e 90 days after moulding. For the flexural strength test, 15x15x50 cm prismatic specimens were moulded and tested 28 e 90 days after moulding. For the modulus of elasticity, 15x30 cm cylindrical specimens were moulded and tested at 28 days.

The compaction and the moulding process was effectuated using the Proctor soils compaction method on intermediate energy level of 1,27 Joules/cm, as the cylindrical specimens were moulded in five layers applying 65 blows of compaction hammer in each layer and the prismatic specimens were moulded in two layers applying 345 per layer. The specimens were cured in a humidity chamber at a relative humidity of 95% and a temperature of around 23°.

3. Results and Analysis

3.1 RCC mixtures proportions

Table 3 shows the proportions employed in the mixtures of the RCC.

Table 3. RCC mixture proportions (kg).

Mixture	Cement	Coarse aggregate			RHA
		38 mm	19 mm	12,5 mm	
M 0/80	1	10,31	2,58	12,89	-
M 0/120	1	6,75	1,69	8,44	-
M 0/160	1	4,97	1,24	6,22	-
M 5/80	1	10,85	2,27	10,85	1,26
M 5/120	1	7,10	1,49	7,10	0,83
M 5/160	1	5,22	1,09	5,22	0,61

3.2 Compaction curves for RCC mixtures

The compaction curves for the RCC mixtures are displayed in Figure 2.

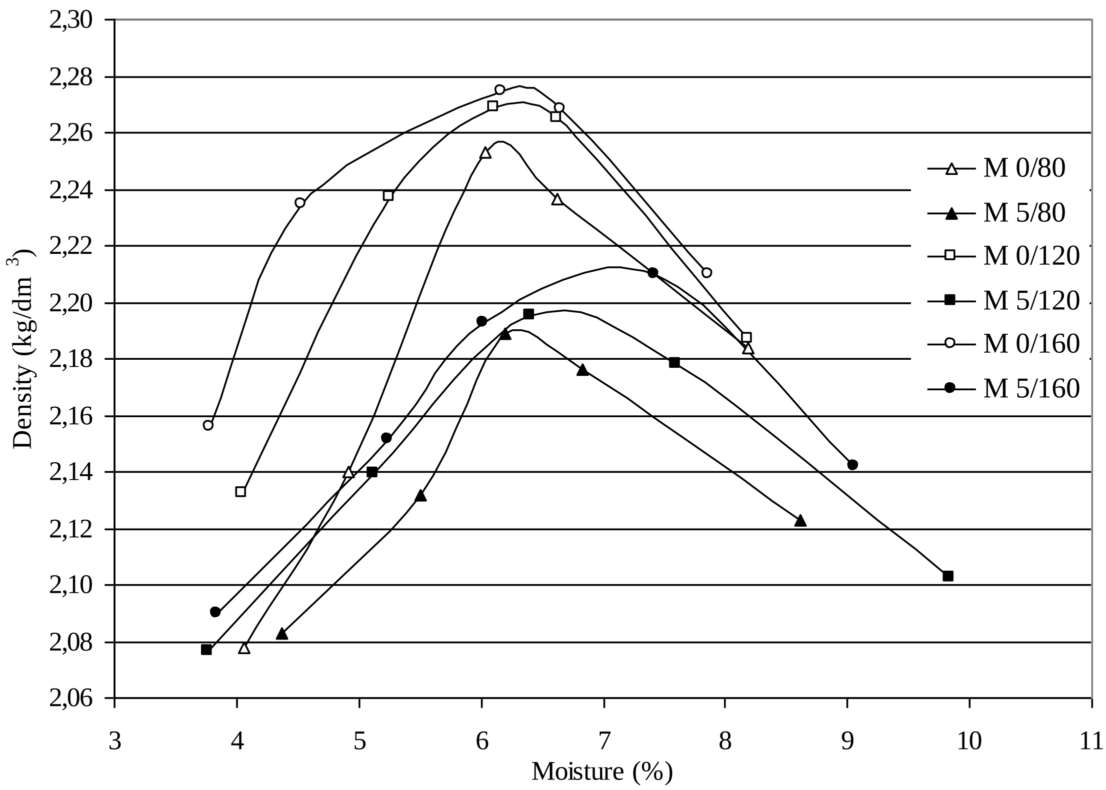

Figure 2. Compaction curves for RCC mixtures.

The M 5 mixtures show higher values of optimum moisture than the M 0 mixtures, due to the fact that during the compaction process the RHA incorporates water in its structure. This water remains disenabled to participate in the lubrication process and therefore the mixtures need more water to be compacted. Likewise the bulk density of the M 5 mixtures is lower than the M 0 mixtures, as the RHA features a far lower specific mass than other the aggregates. This low bulk density is caused, among others, by the higher water amount contained in the mixtures that were added RHA.

The results of the optimum moisture for each mixture are shown in Table 4.

Table 4. Optimum moisture (%) for RCC mixtures.

Mixture	Optimum moisture (%)	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 5/120	6,75	2,20
M 5/160	7,25	2,21

3.3 Compressive strength

The compressive strength test was in accordance with ASTM C39 / C39M, 7, 14, 28 and 90 days after moulding. The results of the compressive strength (MPa) are displayed in Table 5.

Table 5. Compressive strength (MPa) of RCC mixtures.

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

The Figure 3 display the influence of cement content on M 0 and M 5 mixtures compressive strength 28 days after moulding.

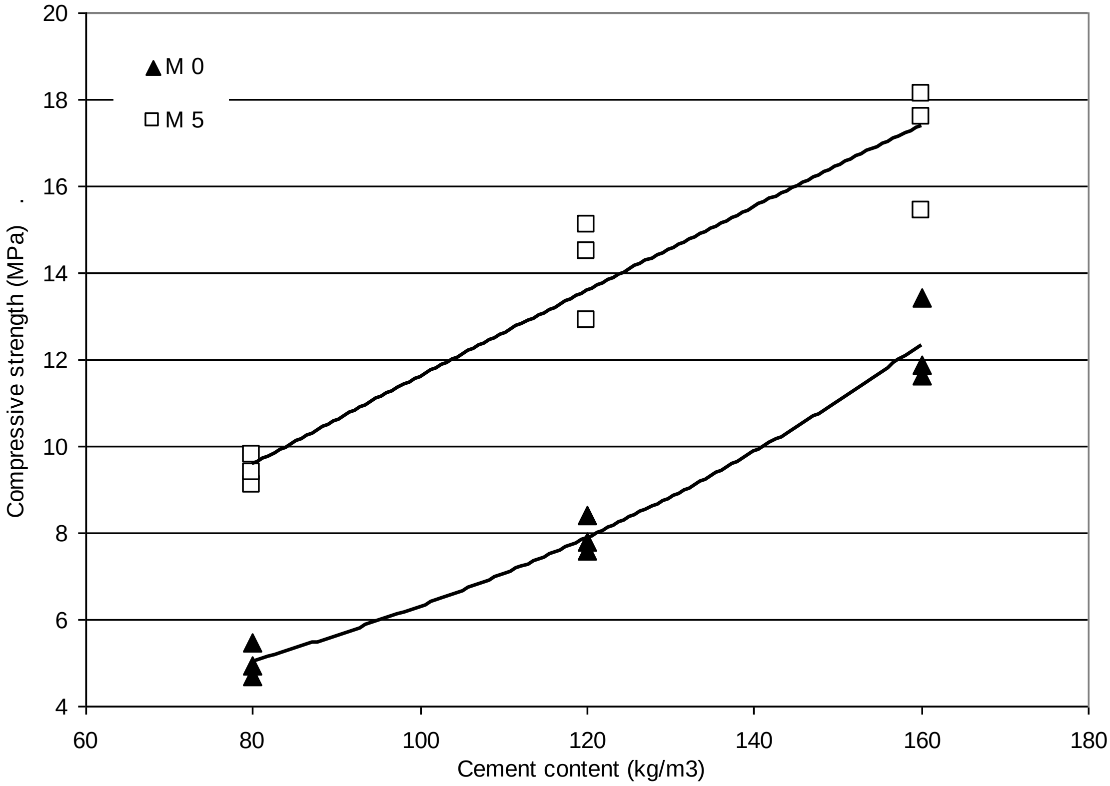

Figure 3: Influence of cement content on M 0 and M 5 mixtures compressive strength 28 days after moulding.

Table 6 intends to analyse the increased compressive strength of the RCC mixtures with 5% of RHA, compared to RCC mixtures without RHA at different curing ages.

Table 6. Compressive strength increase of RCC mixtures.

Mixture	Compressive strength increase (MPa)				Compressive strength increase (%)			
	7 days	14 days	28 days	90 days	7 days	14 days	28 days	90 days
M 80	2,91	3,36	4,4	7,88	83	83	88	135
M 120	4,34	5,19	6,21	8,43	71	72	78	94
M 160	2,79	3,47	4,73	6,27	27	29	38	43

Figure 4 displays the increase of compressive strength 7, 14, 28 e 90 days after moulding.

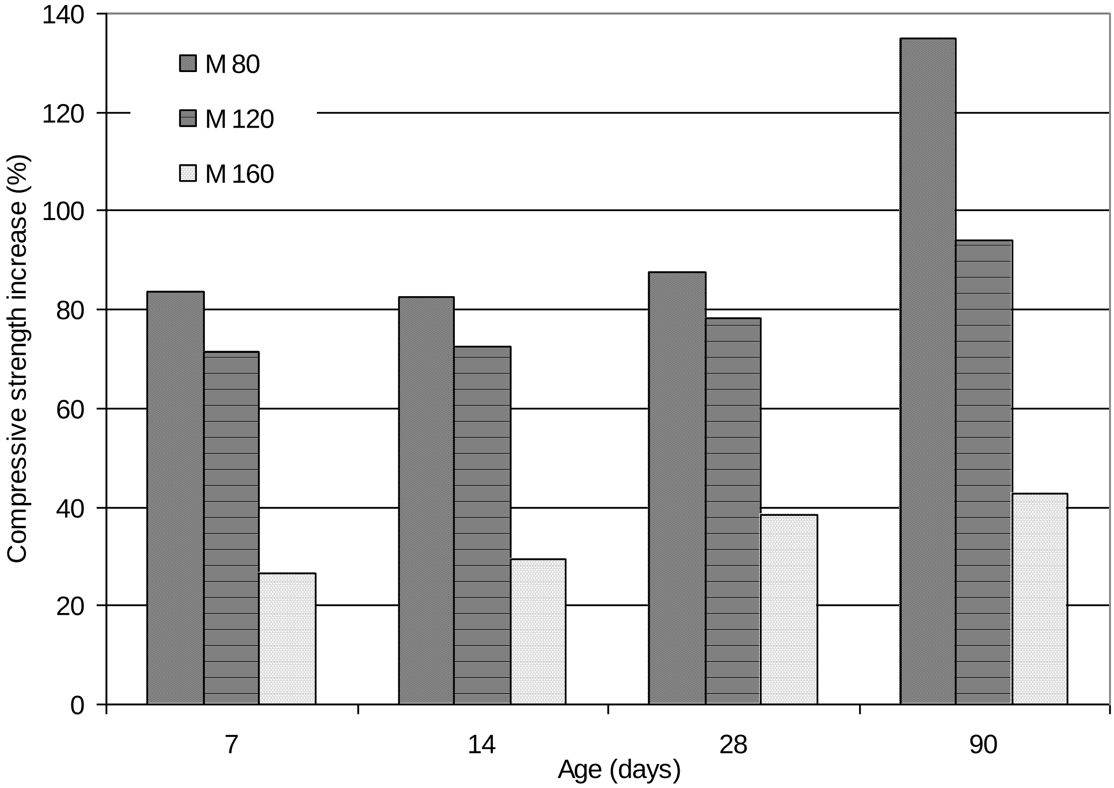

Figure 4: Compressive strength increase (%) of RCC mixtures.

Based on values obtained in Table 6 it can be concluded that the highest compressive strength increase of RCC mixtures occurred 90 days after moulding. This is due to the fact that RHA is a pozzolan that shows a high reactivity with calcium hydroxide, produced by cement hydration forming hydrated calcium silicate 28 days after moulding.

It can be observed in Table 6 and Figure 4 that the highest increase in percentage of the compressive strength, was verified in the RCC mixtures of 80 kg cement content, for all curing ages. It indicates that in mixtures with low cement content, the RHA produces a physical effect, filling the voids of the cement matrix.

3.4 Flexural strength

The flexural strength test was carried out in accordance with ASTM C78, 28 and 90 days after moulding. The values obtained for flexural strength are shown in Table 7.

Table 7. Flexural strength (MPa) of 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

The Figure 5 displays the influence of cement content on M 0 and M 5 mixtures' flexural strength, 28 days after moulding.

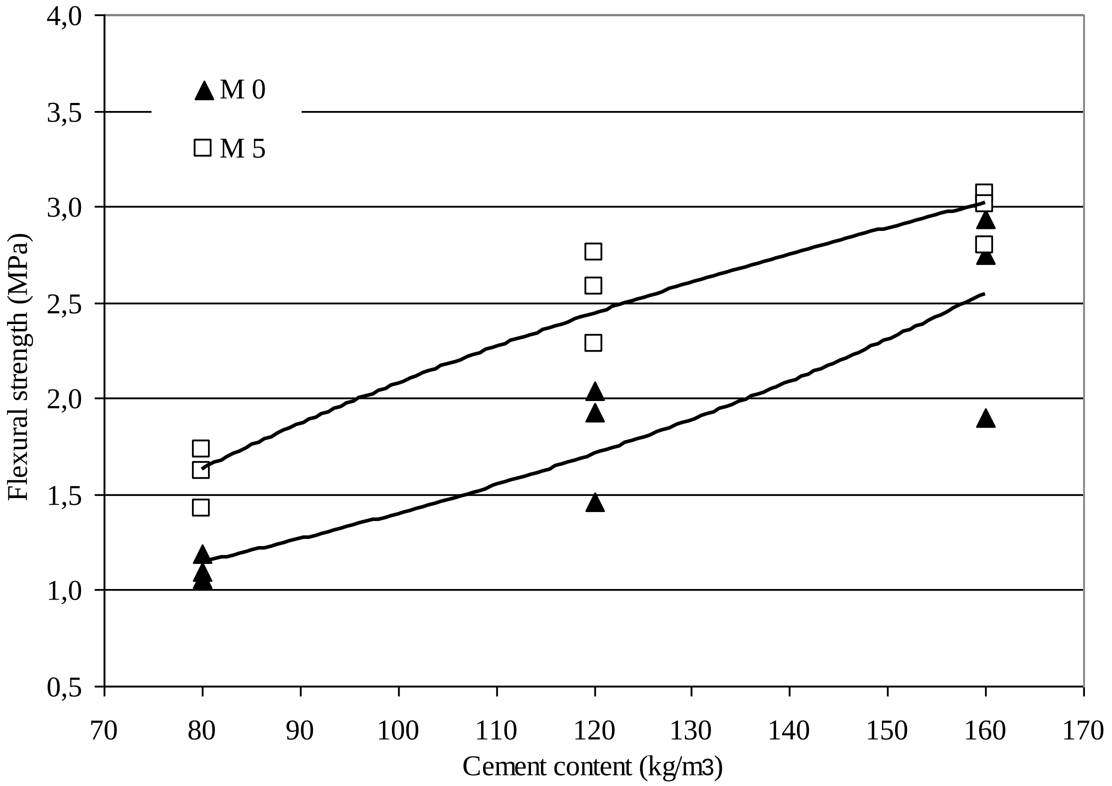

Figure 5: Influence of cement content on M 0 and M 5 mixtures' flexural strength, 28 days after moulding.

The flexural strength increase of RCC mixtures with 5% of RHA versus RCC mixtures without RHA is shown in Table 8.

Table 8: Flexural strength increase of RCC mixtures.

Mixture	Flexural strength increase (MPa)		Flexural strength increase (%)	
	28 days	90 days	28 days	90 days
M 80	0,47	0,78	42	66
M 120	0,73	1,03	40	54
M 160	0,43	1,37	17	50

Figure 6 shows the increase of flexural strength of RCC mixtures 28 and 90 days after moulding.

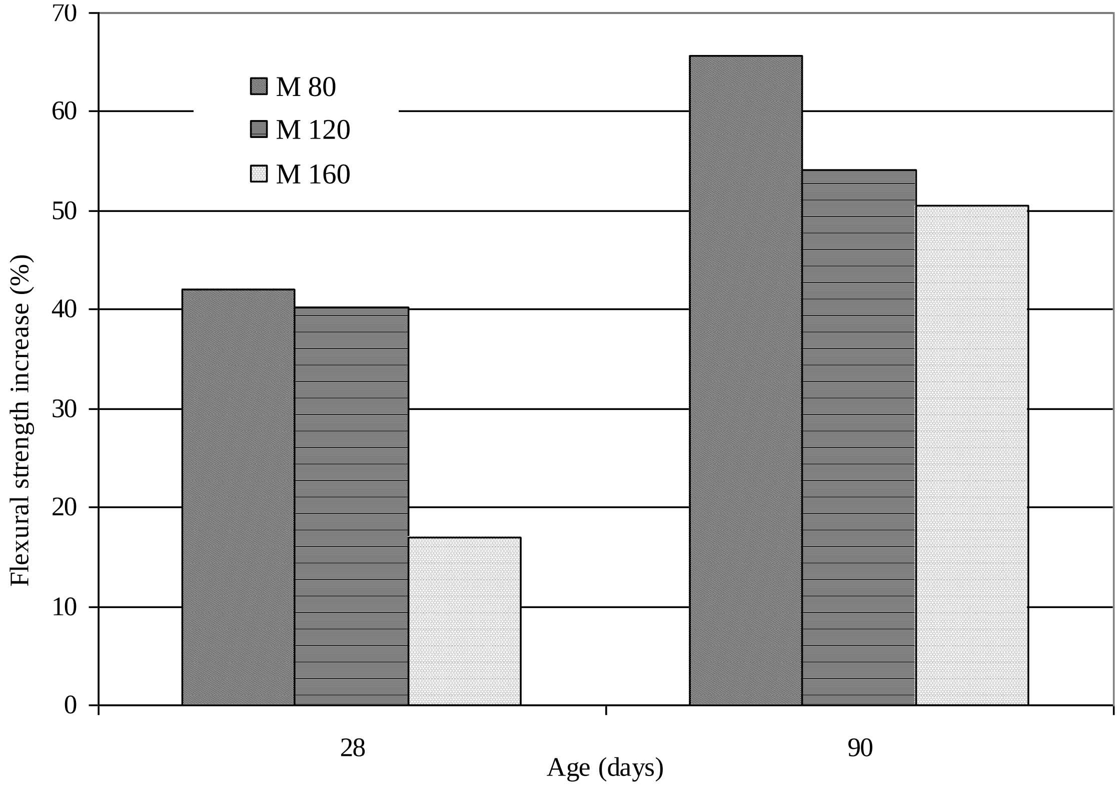

Figure 6: Flexural strength increase (%) of RCC mixtures.

Analysing Figure 6, it can be noted that the flexural strength follow the same trend of compressive strength (Figure 4). The best performance of RHA occurred for the mixtures with 80 kg/m^3 of cement content mainly at 90 days. Showing once more the pozzolanic effect of the RHA.

3.5 Modulus of elasticity

The modulus of elasticity test was undertaken in accordance with ASTM C469, 28 days after moulding. The values for the modulus of elasticity are shown in Table 9.

Table 9. Modulus of elasticity (GPa) of 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 7 shows the influence of cement content on the modulus of elasticity for RCC mixtures.

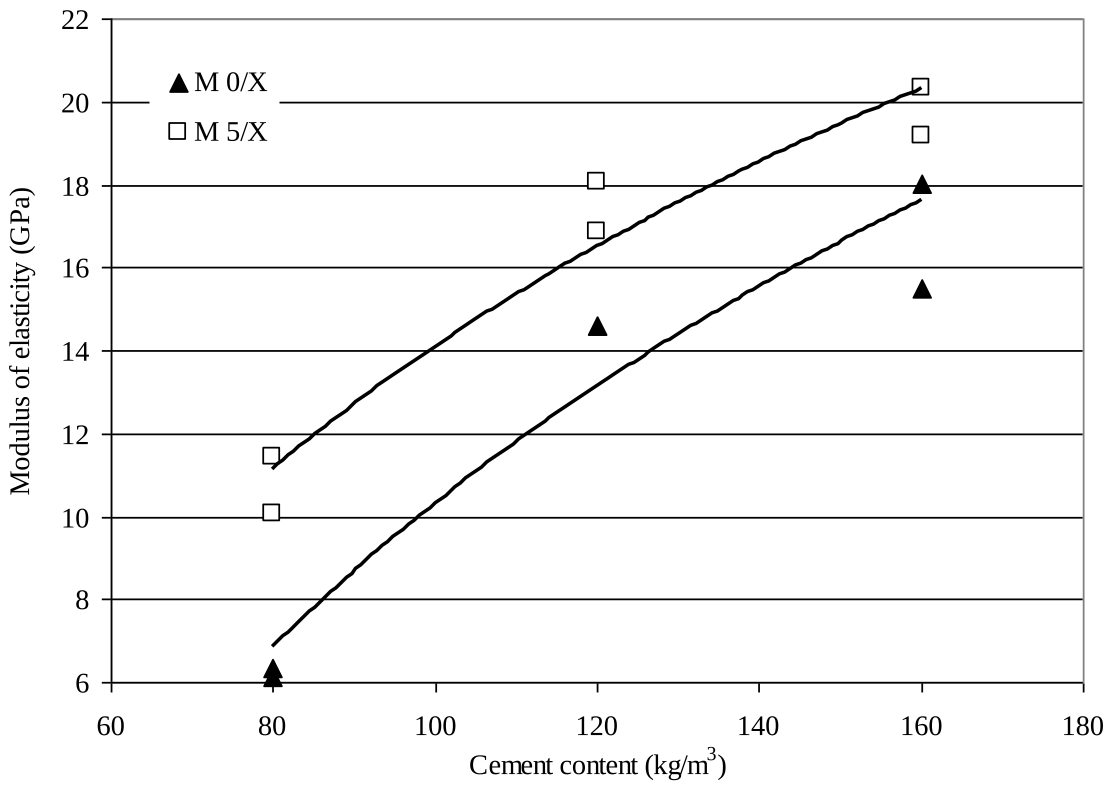

Figure 7: Influence of cement content on M 0 and M 5 mixtures' modulus of elasticity, 28 days after moulding.

The increase of the modulus of elasticity of RCC with 5% of RHA mixtures versus RCC mixtures without RHA is represented in Table 10.

Table 10. Increase of the RCC mixtures' modulus of elasticity

Mixture	Modulus of elasticity increase (GPa)	Modulus of elasticity increase (%)
M 80	4,52	72
M 120	2,85	20
M 160	2,99	18

The major increase in percentage of the modulus of elasticity was observed for mixtures with 80 kg/m^3 cement content, while there is less increase in case of a higher cement dosages.

Figure 8 shows the increase of flexural strength of RCC mixtures 28 days after moulding.

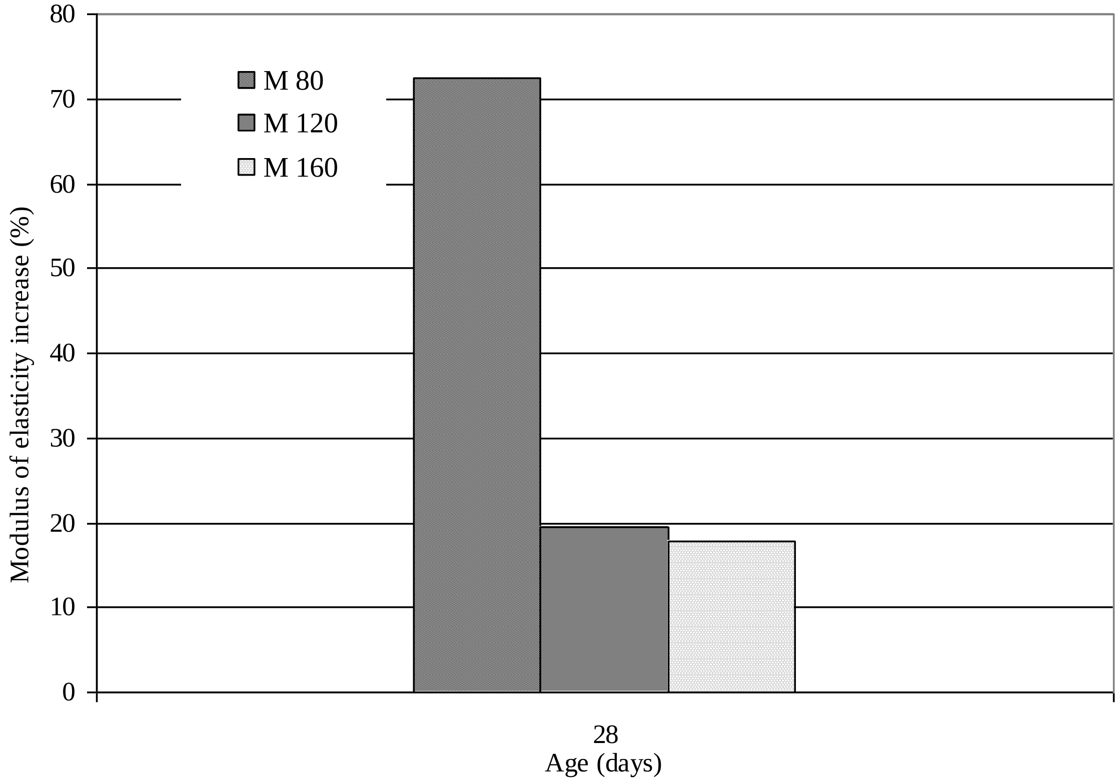

Figure 8: Modulus of elasticity increase (%) of RCC mixtures.

Conclusions

The addition of 5% RHA to RCC causes an increase of the optimum moisture value and decrease of the RCC mixtures' bulk density.

Moreover, it improves the mechanical properties of compressive strength, flexural strength and the modulus of elasticity, irrespective of the investigated cement content.

The major increase in percentage of RCC mechanical strength could be observed 90 days after moulding, independent of the analysed cement content. This evidences the occurrence of pozzolanic reaction.

Finally, the use of RHA in RCC leads to the reduction of cement content for attaining a specific mechanical resistance. Considering these facts, the utilization of this by-product in the construction of highways in rice producing region can contribute to the environmental management of the rice production's commodity chain.

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