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Impact strength and abrasion resistance of high strength concrete with rice husk ash and rubber tires

Resistência ao impacto e à abrasão de concreto de alta resistência com cinza de casca de arroz e borracha de pneus

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Abstract

The paper discusses the application of High Strength Concrete (HSC) technology for concrete production with the incorporation of Rice Husk Ash (RHA) residues by replacing a bulk of the material caking and rubber tires with partial aggregate volume, assessing their influence on the mechanical properties and durability. For concrete with RHA and rubber, it was possible to reduce the brittleness by increasing the energy absorbing capacity. With respect to abrasion, the RHA and rubber concretes showed lower mass loss than the concrete without residues, indicating that this material is attractive to be used in paving. It is thus hoped that these residues may represent a technological and ecological alternative for the production of concrete in construction works.

Keywords: high strength concrete, rice husk ash, rubber tire, impact resistence, abrasion resistance.

Resumo

O trabalho aborda a aplicação da tecnologia do Concreto de Alta Resistência (CAR) para a produção de concretos com incorporação dos resíduos de Cinza de Casca de Arroz (CCA) através da substituição em massa de parte do material aglomerante, e borracha de pneus em substituição parcial do agregado miúdo em volume, avaliando suas influências sobre as propriedades de durabilidade e mecânicas. Para os concretos com CCA e borracha, foi possível verificar a redução da fragilidade através do aumento da capacidade de absorção de energia. Com relação à abrasão, os concretos contendo CCA e borracha apresentaram perda de massa inferior ao concreto sem resíduos, indicando que este material é atrativo para o uso em pavimentação. Contudo, espera-se que estes resíduos venham representar uma alternativa tecnológica e ecológica para a produção de concretos na construção civil.

Palavras-chave: concreto de alta resistência; cinza de casca de arroz, borracha de pneu, resistência ao impacto, resistência à abrasão.

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1. Introduction

The use of High Strength Concrete (HSC) has grown worldwide for structural purposes, and it is employed in building pillars, in dams, in industrial floors, in structural recoveries, in preformed parts, among other uses. According to Libório [1], HSC can provide a gain of useable area, decrease material consumption, reduce the permanent structural load, shorten the execution time and increase the maintenance time.

solid residue disposal has increased in recent years, and the problems that arise from the depletion of natural raw materials have also increased, this has consequently lead to studies on the utilization of industrial residues aiming to reduce its environmental impact and enabling to reduce manufacturing costs.

Rice husk ash (RHA) and used rubber tires are among the residue variety currently generated, this application is aimed not only to reduce material costs, but also to minimize the environmental aspects by striving for sustainability in production processes.

The incorporation of industrial residue to concrete, such as RHA (with high pozzolanic reactivity), besides representing a solution for using by-products from other industries, is also regarded as an efficient replacement material for a part of Portland cement, as it enriches the performance of the final composite.

The use of alternative materials such as slag, fly ash, RHA and silica fume, as well as their combinations, can produce adequate performance concrete for construction works (NEVILLE [2]).

As for scrap tire rubber incorporated into concrete, this presents alternative solutions to minimize environmental degradation by reducing the disposal of scrap tires into nature, reduce costs and improve the performance of products in civil construction.

Residue rubber added to concrete could act as an obstacle in the development of cracks by intersecting the microcracks that appear during concrete hardening, preventing its development (BONNET [3]).

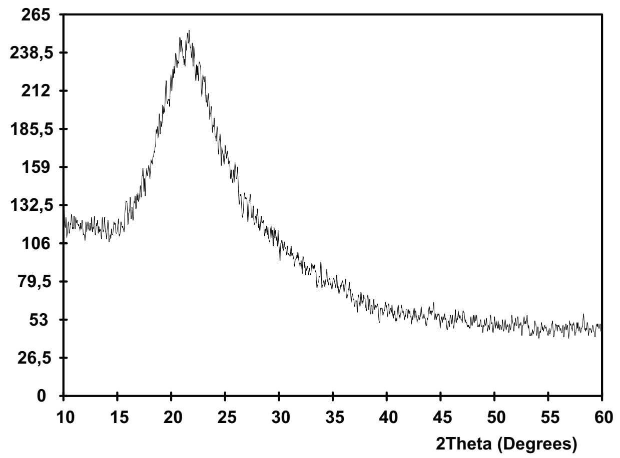
Vanconcelos and Akasaki [4], subjected concrete to several degradation processes, such as the action of water, temperature, salts and acid solution. Their results analysis verified the interference of additions in the prevention of deleterious effects on concrete by incorporating RHA and rubber tire. In general, the study demonstrated that the durability was not compromised with the residue additions, moreover, the rubber was very effective against chemical attack, high temperatures and water entry.

According to Marques et al. [5], their concrete containing rubber, even with lower mechanical strength and tensile strength, when compared to concrete without the residue, showed the mass loss was similar to the reference concrete – hence demonstrating concrete with rubber has good abrasion resistance.

According to Akasaki et al. [6], with respect to the abrasion test, the incorporation of RHA in the concrete for binder replacement ratios of 5% and 10% showed better results than the reference concrete. With respect to the impact resistance tests, Fioriti et al. [7] stated that the breaking behavior of reinforced concrete with rubber is different from the reference concrete, in which significant changes were observed and showed the effective physical participation of tire residues in containing the cracking in the concrete pieces. However, it was not possible to quantify the contribution but regarded the increased energy absorption capacity (toughness) of the concrete with rubber quite meaningful.

The incorporation of RHA and tire rubber residues in concrete offers not only technical advantages, but also social benefits related to mitigating the problems of residue disposal into the environment, which could encourage the development of research investigating the potential of these materials. Thus, the results obtained in this work aim to provide subsidies to the technical environment to foster advancements in the application of these materials.

Figure 1 – Diffractogram of RHA



2. Materials and concrete dosage

2. Rice husk ash

This work used RHA produced in the laboratory of Civil Engineering of Unesp – Ilha Solteira Campus. A burning process was used to obtain a light colored and amorphous ash. It should be mentioned that the process to obtain this material is being patented by the Alternative Building Materials group – MAC/Unesp.

The chemical composition of the ash and the X-ray diffractogram are shown in Table [1] and Figure [1], respectively. No temperature control was used to burn the rice husk and peaks of up to 850 ºC

Table 1 – Chemical characterization of RHA (ABNT (8))

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	NaO	K_2O	Fire loss
RHA	92,99	0,18	0,43	1,03	0,35	0,10	0,02	0,02	2,36

Table 2 – Classification of the tire rubber residue

Normal and auxiliary sieves		Tire rubber residues	
Denomination	Aperture (mm)	% Retained	Denomination
1/4"	6.30	1.90	Very coarse
Nº 8	2.38	45.90	Coarse
Nº 16	1.19	27.20	Medium
Nº 200	0.075	25.00	Fine

were detected during the process. RHA has a light gray coloring and according to Figure [1] the RHA under study is an amorphous material. This is indicated by the baseline deviation between the angles of 15 and 30 degrees.
In this study, after the 30-minute milling process, RHA displayed a median diameter of 11.08 µm measured by a laser granulometer. The milling process used a Gabrielli Mill-2 ball mill containing 50 alumina balls, 18 mm in diameter and total weight of 570 g. The 30-minute milling was set as the baseline for the results presented by Vasconcelos and Akasaki [4], regarding the milling time influence on the RHA particle size.

2.2 Tire residues

Off-road and heavy machinery retreaded rubber tires were used. The rubber tire underwent a screening process and particle-size selection, and were then classified as fine, medium, coarse and very coarse; with the mean particle size used in this study, that is, the residues that passed through a sieve mesh opening of 2.38 mm and retained in the sieve mesh apertures of 1.19 mm. Table [2] shows the tire rubber classification results.
Based on the studies of Vita et al. [9] the same particle size range and tire rubber residue percentage were used to replace the fine aggregate, namely 3% of rubber average (by volume). The description of the average rubber is as follows: elongated shape (as fiber), length mostly less than 10 mm and thickness of about 1 mm.

2.3 Concrete dosage

The following materials comprising the concrete dosage were characterized: Portland cement CP II F 32 (Table [3]), basaltic gravel (Table [4]), natural sand (Table [5]) and polycarboxylate - superplasticizer (Table [6]). The addition of tire rubber (Table [7]) and RHA (Table [8]) were also used in the concrete composition. The procedure used for the HSC dosage composition was proposed by the Canadian researchers Aïtcin [12], called the “Aïtcin Method”. This method is specific for HSC, which improves its parameters through empirical results based on absolute value criteria. The method procedure began by selecting different dosage characteristics:

- Water/binder ratio: relationships proposed between water/binder and resistance;
- Additive: based on the saturation point;
- Coarse aggregate content: according to the typical particle shapes;
- Incorporated air content: by the suggested initial estimate (1.5 %).

Table 3 – Physical characteristics of the cement CP II F – 32 (ABNT (10))

Cement CP II-F-32			Indices obtained	Specifications	
				min.	max.
200 sieve fineness (% retained)			0.14	–	12.0
325 sieve fineness (% retained)			1.4	–	–
Specific surface - Blaine (cm^2/g)			4786	2600	–
Specific apparent mass (g/cm^3)			1.04	–	–
Specific absolute mass (g/cm^3)			3.02	–	–
Paste-like water consistency		grams	135	–	–
		(%)	27.0	–	–
Initial adhesion (h:min)			02:28	01:00	–
Auto-clave expansion (%)			0.042	–	–
Axial compression strength	Mortar consistency	grams	150	–	–
		a/c	0.48	–	–
	Strain (MPa)	3 days	36.1	10.0	–
		7 days	39.5	20.0	–
		28 days	47.4	32.0	–

Table 4 – Composition of gravel particle size (ABNT (11))

Sieves (mm)	% Accumulated retained										
	0.149	0.297	0.595	1.190	2.38	4.76	6.30	9.51	12.70	19.0	25.4
Gravel	100.0	100.0	100.0	100.0	100.0	93.7	74.4	37.2	0.0	0.0	0.0

Maximum diameter (mm)	Finess module	Specific mass	
		Apparent (g/cm^3)	Absolute (g/cm^3)
19.0	6.31	1.504	2.955

Table 5 – Sand grain size composition (ABNT (11))

Sieves (mm)	% Accumulated retained										
	0.075	0.149	0.297	0.595	1.19	2.38	4.76	6.30	9.51	12.7	19.0
Sand	100.0	91.8	62.4	31.8	18.4	4.3	0.4	0.0	0.0	0.0	0.0

Maximum diameter (mm)	Finess module	Specific mass	
		Apparent (g/cm^3)	Absolute (g/cm^3)
2.38	2.09	1.584	2.649

Table 6 – Technical characteristics of the additive

Main function	Solids content	Maximum dosage	pH	Specific mass
Superplasticizer	35%	2% relative to the cement weight	4.3 ± 0.5	1.08 kg/l to 20 °C

Table 7 – In-natura tire rubber particle size composition (ABNT (11))

Sieves (mm)	% Accumulated retained											
	0.075	0.149	0.297	0.595	1.19	2.38	4.76	6.30	9.51	12.7	19.0	25.4
Rubber	100.0	99.5	96.2	89.5	69.1	21.0	2.3	0.9	0.3	0.0	0.0	0.0

Maximum diameter (mm)	Finess module	Specific mass	
		Apparent (g/cm^3)	Absolute (g/cm^3)
4.76	3.78	0.33	1.15

Table 8 – Physical characteristics of RHA (ABNT (8))

Rice husk ash			Specifications	
			min.	max.
	Apparent density (g/cm^3)	0.40	–	–
	Absolute density (g/cm^3)	2.16	–	–
	325 Sieve Finess (% retained)	3.4	–	–
	Grain size (microns)	12.38	–	–
Pozzolanic activity indices	Required water (%)	114.6	–	110.0
	With cement (%)	60.7	75.0	–
	With lime cal (MPa)	4.9	6.0	–
	Humidity of sample (%)	1.90	–	3.0

Table 9 – Composition of concrete dosages

Materials	Control	Control/Rubber	5% RHA	RHA/Rubber
Cement (kg/m^3)	466.67	466.67	443.33	443.33
RHA (kg/m^3)	–	–	23.33	23.33
Coarse aggregate (kg/m^3)	1125.00	1125.00	1125.00	1125.00
Fine aggregate (kg/m^3)	812.31	732.60	801.99	722.28
Tire rubber (kg/m^3)	–	34.50	–	34.50
Water (kg/m^3)	140.00	140.00	140.0	140.00
Water/agglomerate (a/agl)	0.30	0.30	0.30	0.30
Superplasticizer additive (kg/m^3)	3.74	3.74	5.35	5.35
% Superplasticizer/cement (mass)	0.80%	0.80%	1.20%	1.20%
% Mineral addition (mass)	–	–	5.00%	5.00%
%Mortar content	54.00%	52.00%	54.00%	54.00%
Coarse aggregate in relation to fine aggregate	56.12	58.65	56.44%	58.99%
% Rubber m^3 (volume)	–	3.00%	–	3.00%
% Rubber/fine (volume)	–	10.88%	–	11.04%
% Rubber/coarse (volume)	–	7.67%	–	7.67%

Next, the water/binder and additive ratio were correlated to determine the amount of binder to be used in the dosage, and the remaining volume to be filled in a cubic meter was completed with fine aggregates. The mortar and coarse aggregate levels were evaluated by the method used by Helene and Terzian [13]. For the sake of clarity, the concretes used in this study were classified under the following conditions:

- Concrete with no (0%) mineral incorporated – **Control**;
- Concrete with no (0%) mineral incorporated and with 3% rubber – **Control/Rubber**;
- Concrete with 5% rice husk ash – **5 % RHA**;
- Concrete with 5% rice husk ash and 3% rubber – **RHA/Rubber.**

Table [9] shows the concrete dosage compositions used. After the materials were quantified the concrete production and preparation of the specimens began. The concretes were produced in an inclined axis mixer, according to ABNT [14].

Figure [2] shows the cylindrical specimens molded (30 cm x 10 cm diameter x height) for the abrasion test, performed at 28 days of age. For the impact resistance test performed at 7 and 28 days of age, prismatic (plates) of 5 cm x 15 cm x 30 cm were molded, shown in Figure [3]. Cylindrical specimens of 10 cm x 20 cm (diameter x height), in Figure [4] were also molded for the compressive strength and tensile strength tests, and thereafter a correlation analysis between resistance and the values obtained in the impact and abrasion tests.

After molding, all specimens were coated in plastic film and kept in the lab for approximately 24 hours. After the molds were removed, the specimens were placed in a moist chamber, according to ABNT [15], until the date of the tests.

Figure 2 – Molding specimen for abrasion test (30 cm x 10 cm)

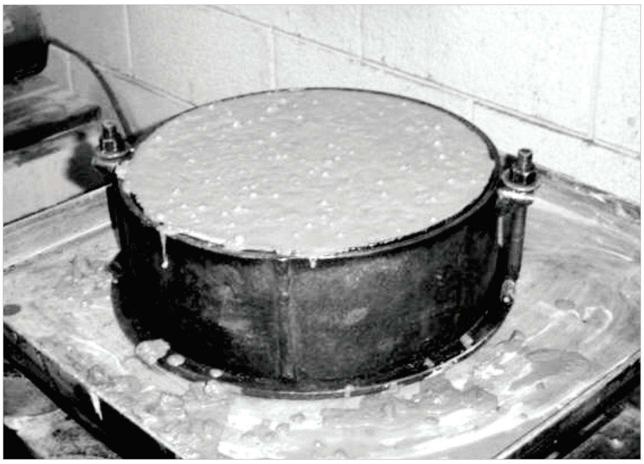
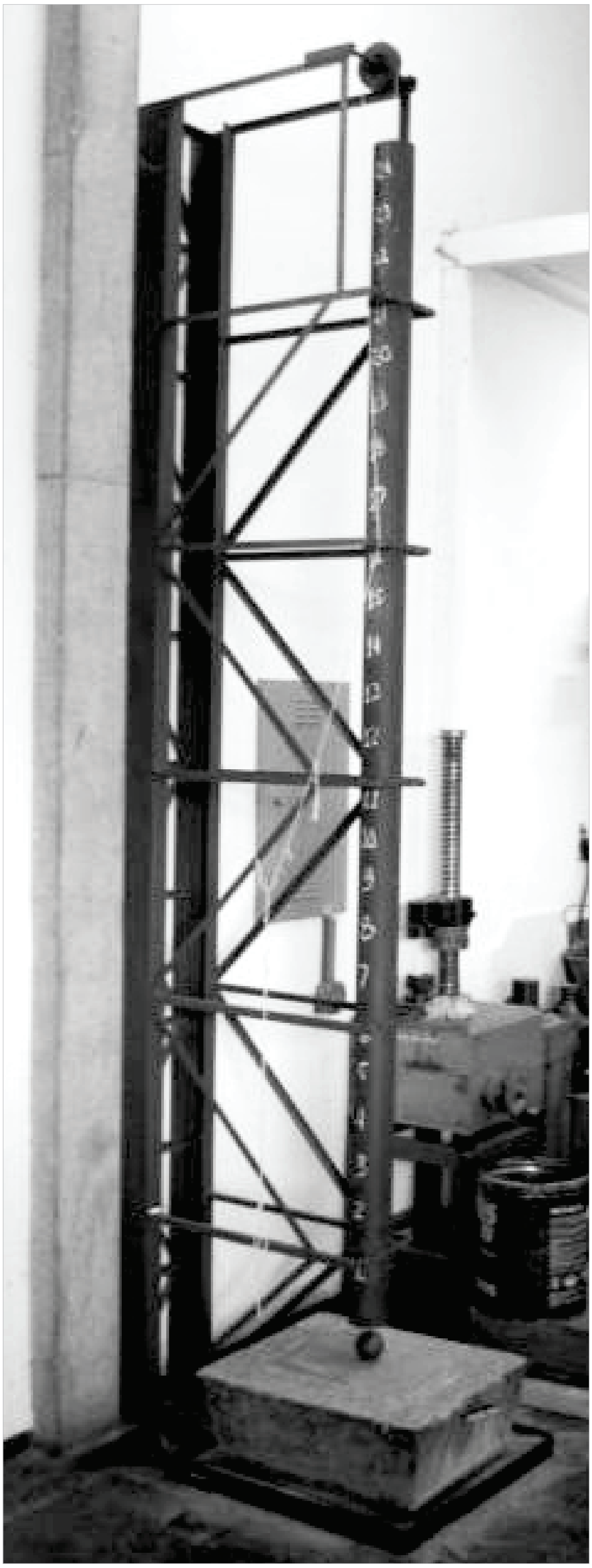


Figure 3 – Molding specimens for impact test (5 cm x 15 cm x 30 cm)

Figure 4 – Specimens for tensile and compression tests (10 cm x 20 cm)

Figure 5 – Apparatus used in impact test



3. Test methodology

3.1 Impact resistance

The impact resistance of HSC was determined according to ABNT specifications [16]. This method was based on the free fall of a sphere of known mass on the center of a concrete specimen placed in a standardized sandbox.
Figure [5] shows the equipment used in the impact resistance test, which consists of a 2.20m tube appended to the wall by a metal ball attached to a cord inside the tube weighing 0.5 kg, passing through a pulley and a metal box containing sand and located below the tube where the specimen was placed. The test was performed considering the free fall of the ball, where a height change of the fall occurs. Three test specimens per concrete dosage were used in this test.
The impact resistance was determined by the energy sum for the appearance of the first crack in the upper face and/or specimen rupture. Equation [1] was used in this paper:

$$Ei = h \times m \times a \quad (1)$$

Where:
Ei = Impact energy (N.m ou J);
h = Falling height (m);
m = Sphere mass (kg);
a = Gravity acceleration (m/s²).

3.2 Abrasion resistance

The abrasion resistance test was based on the U. S. Corps of Engineers method, known as the "*Abrasion – Erosion Resistance of Concrete*" (LCEC [17]). The apparatus used for this test consists of an electric motor, a stirring paddle, and a steel cylindrical container

Figure 6 – Abrasion resistance testing apparatus

to hold the test specimen, to which steel balls were later added in order to provide the abrasive wear. Figure [6] shows the device used for the abrasion resistance test.
The wear was calculated according to the mass change percentage, for 71 hours of testing, weighed prior to starting the test and after 10, 24, 48 and 71 hours. A single test specimen was used in this assay per concrete dosage.

3.3 Tensile strength and compressive stress

The mechanical strengths were obtained according to the following specifications: compressive stress (ABNT [18]) and tensile strength by diametral compression (ABNT [19]). These tests were performed at 3, 7, 28 and 63 days of age, and the values were established through the arithmetic mean of three specimens by age and concrete dosage.

4. Results and discussion

Tables [10] and [11] show the impact resistance results of HSC. It was found that for the HSC with or without mineral incorporation and without the addition of rubber, a smaller number of impacts was required (lower energy) for the appearance of the first cracking, compared to the first cracking of HSC with rubber, regardless of age.
It was seen that the HSC with mineral incorporation had higher impact resistance when compared to the Control dosage, regardless of age and order of crack observations (first and last crack). This also occurred for the HSC with mineral and rubber incorporation.
As for the HSC with mineral and rubber incorporation, there was an impact resistance gain from the last crack, with values ranging from 9% to 20% at 28 days of age, compared to the HSC with only mineral incorporation. While the Control/Rubber dosage decreased by 10% in impact resistance, at the same age.
After the next impact application related to the first crack, the last crack was determined, thickness between 0.2 mm to 0.5 mm for the HSCs and with and without mineral incorporation, with the complete sectioning of the specimens (plates). The HSCs with rubber showed a crack thickness of up to 0.5 mm, reaching a maximum fall height of up to 2.20 m, with no complete sectioning of the specimens. Figure [7] shows some specimens at the end of the impact resistance test.

Table 10 – Results of impact resistance of high strength concrete (1st crack)

Dosage	1st crack observed					
	Height of fall (m)		Impact resistance (J)		Thickness (mm)	
	7 days	28 days	7 days	28 days	7 days	28 days
Control	1.5	1.6	59.5	67.5	0.3	0.3
Control/Rubber	1.6	1.7	67.5	76.0	0.05	0.05
5% RHA	1.8	1.9	85.0	94.5	0.1	0.1
RHA/Rubber	1.9	2.0	94.5	104.5	0.05	0.05

Table 11 – Results of impact resistance of high strength concrete (last crack)

Dosage	Last crack observed						Observations
	Height of fall (m)		Impact resistance (J)		Thickness (mm)		
	7 days	28 days	7 days	28 days	7 days	28 days	
Control	1.7	1.8	76.0	85.0	0.5	0.5	Fully sectioned
Control/Rubber	1.8	1.9	94.5	94.5	0.2	0.5	Did not section
5% RHA	2.0	2.1	104.5	115.0	0.5	0.5	Fully sectioned
RHA/Rubber	2.1	2.2	115.0	126.0	0.2	0.2	Did not section

Figure [8], shows the abrasion resistance results of the concrete after 28 days of age, obtained by the weight loss percentage by abrasion wear.
Figure [8], shows that there was a mass loss decrease in all the testing periods of HSC with mineral incorporation, in relation to the mass loss shown in the Control HSC. The mass loss, in 71 hours, was 34% lower for the dosage with 5% RHA, compared to the Control HSC. It is assumed that the least amount of hydrated cement in HSC with mineral incorporation was offset by the actions of the micro-filer effect.
In relation to the HSC with rubber, all dosages showed lower weight loss results when compared to the HSCs without rubber.
Comparing the final wear percentage of the Control/Rubber dosage, of 1.41%, subjected to the abrasion test, with the dosage results with RHA/Rubber, of 0.29%, it can be stated that the addition of RHA contributes to improve the abrasion resistance of the concrete.
Thus, it can be said that the concrete with RHA and rubber showed good performance when subjected to abrasion wear, indicating that this type of concrete can be used, for example, in paving. Figures [9a, b, c, d], show the sample specimens after the abrasion resistance test.
With respect to the mechanical strength tests, in Figures [10] and [11], the dosages with the mineral incorporation were lower than the tensile strength and compressive strength values throughout the ages analyzed, compared to the Control, showing it is a more brittle material.
As for dosages with rubber incorporation, higher values were found between the tensile strength and compressive strength values, compared to the HSC without rubber, which showed greater ductility.
At 7 days, the dosage with RHA/Rubber demonstrated higher values between tensile and compressive strength, when compared to dosing with 5% RHA, at 63 days of age.
The Control/Rubber dosage showed higher values for tensile strength and compressive strength than for the dosage with RHA/Rubber, at the ages analyzed, proving to be less brittle.
Correlating impact strength with mechanical compression and tension strength, it was noticed that the results do not follow the same tendency with the rubber dosages, that is, the dosages RHA/Rubber and Control/Rubber had higher impact energy absorption than

Figure 7 – (a) Specimen with last crack observed (0.2 mm) in RHA/Rubber dosage; (b) Specimen sectioned at the end of the dosage control test

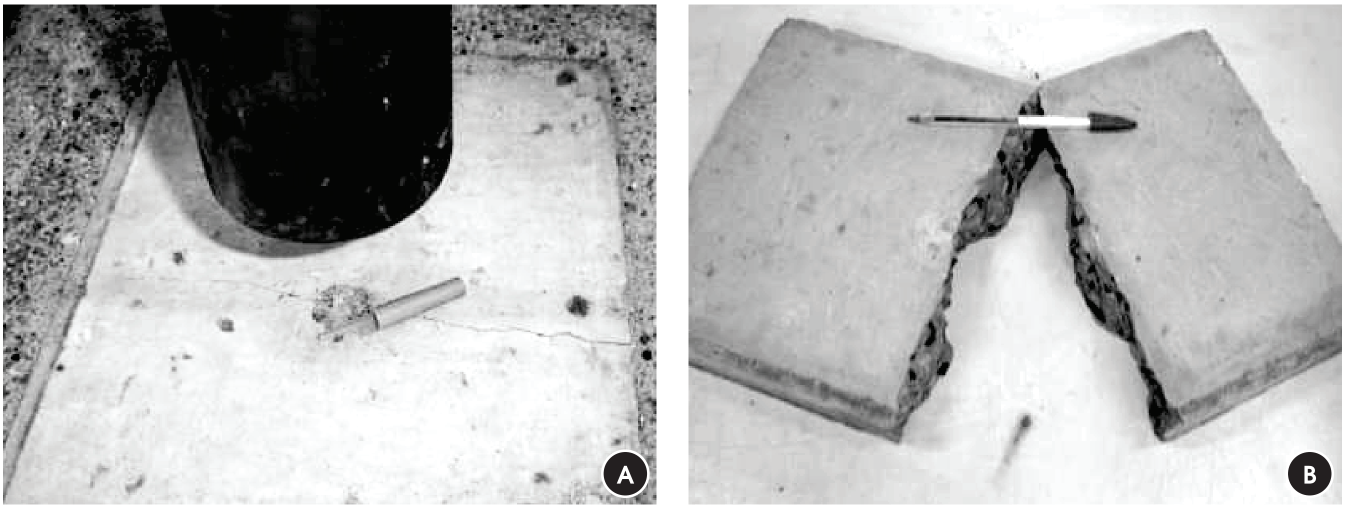


Figure 8 – Abrasion resistance of HSCs

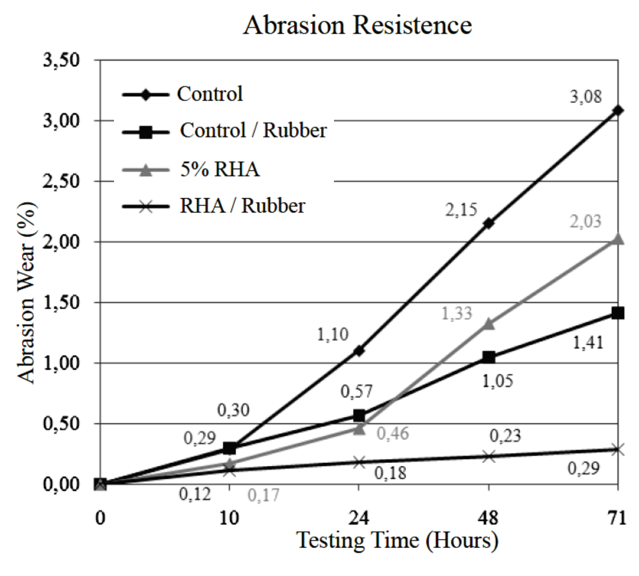
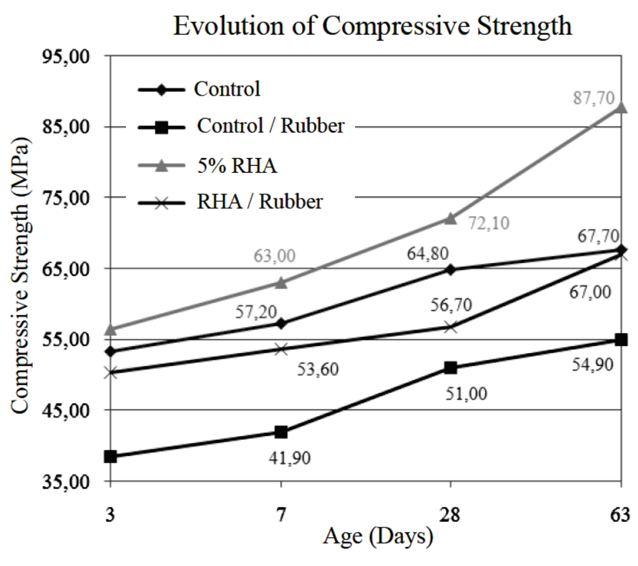


Figure 10 – Compressive strength of HSCs



the Control dosage, thus its mechanical strength was the lowest. The same cannot be said for the dosage with 5% RHA, which had energy absorption practically equal to the RHA/Rubber, and which reached the highest compression and tension mechanical resistance values.

Correlating wear by abrasion with mechanical strength, it was noted that the dosages RHA/Rubber and Control/Rubber showed the lowest wear and the lowest compressive strength and tensile strength values. While the dosage with 5% RHA had a wear value that was only lower than the Control, showing the highest mechanical strength values.

Given the correlations, we can say that the dosages containing RHA as well as the dosages with rubber have higher energy absorption

Figure 9 – (a) Wear Abrasion – Control; (b) Control/Rubber; (c) 5% RHA; (d) RHA/Rubber

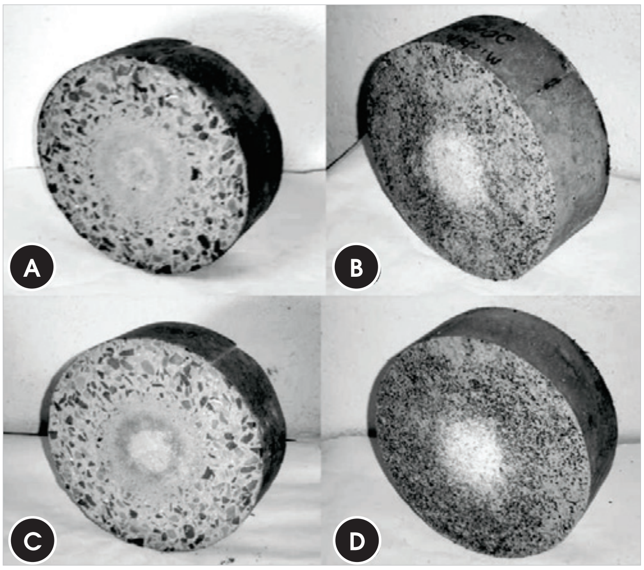
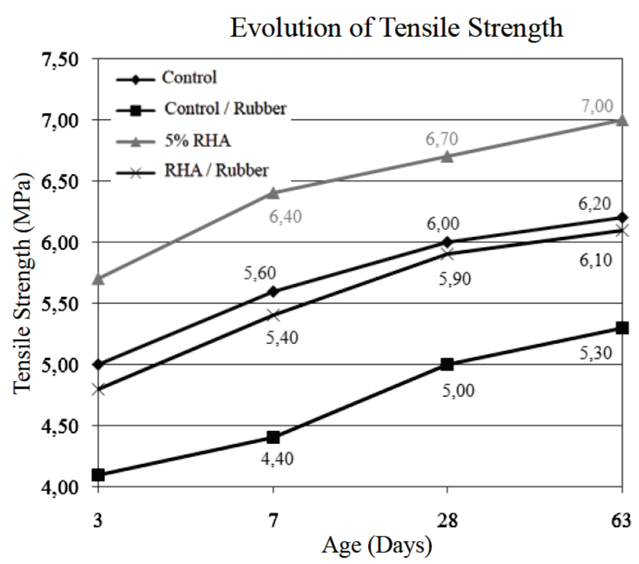


Figure 11 – Tensile strength of HSCs



capacity (toughness) and less wear abrasion when compared to the Control. Thus, the highest mechanical strength values in concrete do not necessarily indicate that the concrete should have a higher energy absorption capacity and yield lower abrasion wear.

5. Conclusions

With respect to the impact test, the concretes with RHA and rubber outperformed the dosage Control/Rubber. Regarding the additions, it can be said that the concrete with RHA outperformed the Control concrete.
The abrasion test results for the concrete containing RHA and rubber showed lower mass loss than the concretes without rubber and the Control/Rubber concrete.
As for the breaking behavior resulting from the impact tests, it can be concluded that the concretes with rubber addition showed better ductility, observed by the energy absorption capacity increase, when compared to concrete without the addition of rubber.
The incorporation of RHA and tire rubber residue to HSC demonstrated its feasibility to be used in paving, mainly due to the good performance of the properties studied. However, it is hoped that these residues may indeed represent a technological and ecological alternative for concrete production in civil construction.

6. Bibliographic references

[01] LIBÓRIO, J. B. L. Análise das propriedades mecânicas de concretos com agregados de Dmáx ∅ 6,3mm e com diferentes tipos e teores de sílica. In: Congresso Brasileiro do Concreto, 45, 2003, Vitória, 2003, Anais, Vitória, 2003. (CD ROM).

[02] NEVILLE, A. Propriedades do concreto. 2.ed. São Paulo: Pini, 1997.

[03] BONNET, S. Materiaux cimentaires a haute deformabilite par incorporation de granulats issus du broyage de pneus usages, França, 2004, Tese (doutorado) – Universite Toulouse III – Paul Sabatier, 280p.

[04] VASCONCELOS, A. R. B.; AKASAKI, J. L. Análise da durabilidade do concreto de alto desempenho com adição de Rice Husk Ash e Rubber de pneu. Ambiente Construído (Online), v. 10, p. 77-90, 2010.

[05] MARQUES, A. C.; NIRSHCL, G. C.; AKASAKI, J. L. Propriedades mecânicas do concreto adicionado com Rubber de pneus. Holos Environment, Rio Claro, v. 6, n.1, 2006.

[06] AKASAKI, J. L.; RICCI, E. C.; VASCONCELOS, A. R. B.; MACEDO, P. C. Avaliação da adição de resíduo agroindustrial como alternativa ecologicamente correta para a construção civil. In: Jornadas Sudamericanas de Ingeniería Estructural, 33, 2008, Santiago – Chile, 2008, Anais, Santiago-Chile, 2008. (CD_ROM).

[07] FIORITI, C. F.; INO, A.; AKASAKI, J. L. Análise experimental de blocos intertravados de concreto com adição de resíduos do processo de recauchutagem de pneus. Acta Scientiarum. Technology (Online), v. 32, p. 237-244, 2010.

[08] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. Materiais pozolânicos – Requisitos NBR 12653, Rio de Janeiro, 2012.

[09] VITA, M. O.; MACEDO, P. C.; AKASAKI, J. L.; FAZZAN, J. V.; MARTINS, I. R. F. Influência da adição de resíduo de Rubber pneumática em concreto de alto desempenho. In: Congresso Brasileiro do Concreto, 49, 2007, Bento Gonçalves, 2007, Anais, Bento Gonçalves, 2007. (CD-ROM).

[10] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. Cimento Portland composto – Especificação – NBR 11578, Rio de Janeiro, 1997.

[11] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. Agregados – Determinação da composição granulométrica – NBR NM 248, Rio de Janeiro, 2003.

[12] AITCIN, P. C. Concreto de alto desempenho. São Paulo: Pini, 2000.

[13] HELENE, P.; TERZIAN, P. Manual de dosagem e controle do concreto. São Paulo: Pini, 349p., 1993.

[14] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. Preparação de concreto em laboratório – Procedimento – NBR 12821, Rio de Janeiro, 2009.

[15] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. Procedimento para moldagem e cura de corpos de prova – NBR 5738, Rio de Janeiro, 2003.

[16] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. Determinação da resistência ao impacto de piso cerâmico – NBR 9454, Rio de Janeiro, 1986. (norma extinta).

[17] LABORATÓRIO CESP DE ENGENHARIA CIVIL (LCEC). Avaliação da resistência a abrasão de superfícies de concreto submersas. Ilha Solteira, 1983. nº. C-38/83. (relatório não publicado).

[18] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. Concreto – Ensaios de compressão de corpos de prova cilíndricos – NBR 5739, Rio de Janeiro, 2007.

[19] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. Concreto e argamassa – Determinação da resistência à tração por compressão diametral de corpos de prova cilíndricos – NBR 7222, Rio de Janeiro, 2011.