VEGETABLE RESIDUE AND PORTLAND CEMENT CHEMICAL COMPATIBILITY BY ULTRASONIC PULSE VELOCITY (UPV)

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ABSTRACT

Inhibitory substances present in vegetable residues can strongly affect the kinetics of the hydration reactions of Portland cement compounds. Earlier researches concerning the knowledge of the chemical compatibility between vegetable residues and inorganic binder were carried out by means of a hydration curve. The parameters evaluated include maximum temperature and time elapsed, maximum slope of the hydration curve and the area below the curve. Besides, the composite hydration curve was compared to the cement paste curve. In this research work it was proposed an alternative method of investigating vegetable residues and Portland cement compatibility. Setting and hardening of cement paste and several vegetable residues, combined or not with catalyst, were daily monitored by ultrasonic pulse velocity (UPV). Mathematic models showed the sensibility of that method in detecting deleterious effects caused by a non compatible vegetable residue on cement structure and the influence of the cement type as well as the catalyst on the composite performance.

Keywords: vegetable particles, composite, ultrasonic pulse velocity (UPV)

INTRODUCTION

Several vegetable species employed in Brazil as raw material like eucalyptus for cellulose and paper production, pines for pencils and furniture production, bamboo for rural constructions and handcraft, generate large amounts of residues. Great part of the generated residues is not forwarded to commercial applications, contributing to the environmental impacts.

Natural resources exploitation and residues availability associated to environmental impacts is one of the most important concerns of the building construction business. Mineral aggregates production provokes environmental damages and landscape degradation, as well as an increasing grows of the transport cost due to the distances between the exploitation areas and the consumption centers.

Mineral aggregates are generally considered chemically non reactive with inorganic binder as Portland cement. In the other hand, vegetable particles shows high reactivity with the binder due to theirs chemical constitution. This reactivity is recognized as chemical incompatibility, indicating a global result of extremely very complex reactions which takes place between the vegetable particles and the inorganic binder.

The efficiency of these reactions depends on the vegetable specie characteristics, on the cement type and the action of others parameters (catalyst type and its content, cure type, water content, etc.).

Earlier investigations carried on chemical compatibility determination between vegetable particles and Portland cement looked for the efficiency of the reactions by through the mixture hydration curve parameters (SANDERMANN, W. et al., 1960). Inhibitory indexes were then proposed by researchers, considering the maximum temperature reached by the mixture, the time elapsed for that occurrence, the maximum curve slope and the surface under the curve (WEATHERWAX & TARKOW, 1964; MOSLEMI & LIM, 1984; MILLER & MOSLEMI, 1991). All of these parameters were compared with those related to the cement paste hydration curve.

However, in laboratory conditions, particles size and mixture ratio (cement:vegetable particles:water) are very different from those observed in commercial applications.
Compression strength was also proposed as a parameter aiming to contribute to a comprehensive approach for vegetable particles and Portland cement interaction (LEE et al., 1987; LEE & SHORT, 1989). This second alternative requires a very large time interval for composite properties evaluation (in general 28 days).
Material properties evaluation by means of non destructive methods (NDE) as ultrasonics are largely employed on homogeneous materials (steel) or even for those with a more complex structure (wood and concrete). NDE can also be applied to vegetable particles and Portland cement composites properties determinations, allowing detecting structural changes during cement hydration (BERALDO, 1999).
A poor interaction between vegetable particles and Portland cement can generate a weak signal or even its absence on screen, denoting an unsatisfactory ultrasonic pulse velocity (UPV) across the composite sample.
The aim of this research work was to evaluate the UPV behavior associated to specimen age for composites produced from eucalyptus, pinus and bamboo particles combined with two different Brazilian Portland cements. UPV analysis was proposed as an alternative to hydration curve test to evaluate chemical compatibility between vegetable particles and Portland cement.

METHODOLOGY

Vegetable particles

Eucalyptus particles (a mixture of *E. saligna* and *E. tereticornis* species) obtained from 30 years old trees were collected at a lumbering sawing facility. Due to the age of the trees, most of the particles were taken from the heartwood region. *Pinus caribaea* specie is largely employed in pencil production. Particles were generated after pencil fabrication at Faber Castell Company. The trees were also of 30 years old. Bamboo stems from *Dendrocalamus giganteus* specie, aged of 5 years old, were cut and particles obtained from a hammer mill.
Particles were screened, selecting the sizes smaller than 2.4 mm diameter. Particles were air dried during 2 weeks before composite production.

Particle characteristics

Particles size distribution was obtained according to the Brazilian standard NBR7211/83. Moisture content and particles density were presented in Table 1 (average of three replications).

Table 1 – Moisture content and density of particles.

Particles	Test	
	Density (g/cm^3)	Moisture content (%)
Bamboo	0,22	3,09
Eucalyptus	0,25	4,03
Pinus	0,15	5,20

Particles treatment

Particles were employed at natural conditions (without treatment) as well as after a hot water treatment (2 h at 80 ºC). For both treatments it was added calcium chloride at 3% (in relation to the cement mass).

Cement types
Two Brazilian Portland cement were employed in the experiment part of this research work - CP-II-E-32 (cement compound with blast furnace slag) and CP-V-ARI (cement of high initial strength). Cements characteristics are displayed on the standards NBR 11578 and NBR 5733, respectively.

Mixture ratios
It was calculated the mass necessary to fill 4 cylindrical moulds (50 mm diameter and 100 mm height) according to the standard NBR 7215. Mass ratio was kept at 1:0.37:0.70. Also was kept at 1:0.70 (both cements) and 1:0.28 (CP-II-E-32) and 1:0.33 (CP-V-ARI).

Specimens
Mixtures were prepared according to the standard NBR 7215 and placed in the cylindrical moulds and applying 20 impact strokes for compaction, for each one of the 4 layers (figures 1 e 2).


Figure 1 – Mixing device


Figure 2 - Compaction in the cylindrical

Hydration curve
PT 100 thermocouples were axially introduced at 30 mm depth into the three specimens of each mixture. Temperature data were recorded by a datalogger Novus at each 5 minutes interval (figures 3 e 4).

Figure 3 – Datalogger Novus

Figure 4 - cylindrical moulds with PT 100

Ultrasonic pulse time

The time elapsed for UPV to cross the fourth specimens of each mixture was recorded by means of an Ultrasonic Tester Steinkamp model BP 7. Exponential transducers with 45 kHz resonance frequencies were placed at the basis of the specimens. Data were recorded during 14 days (figure 5).

Figure 5 – Ultrasonic tester Steinkamp model BP7

Cure conditions

After 24 h specimens were de-moulded, identified and weighted. The cure was conducted during one week in a wet chamber (90% relative humidity), and for more one week in laboratory environment.

Statistical analysis

An analysis of variance (ANOVA) was applied to evaluate the influence of the parameters (particles, cement and treatment types) on composite strength. Means were compared by Tukey´s test at 95% of probability.

Compression test

Old specimens were submitted to a compression test (NBR 7215) in a universal device **a**t 14th day (figure 6).

Figure 6 – Compression test

RESULTS AND DISCUSSION

Figure 7 show the distribution size curve of vegetable particles. Particle fineness was very closely: pinus (3.19), bamboo (3.27) and eucalyptus (3.07).

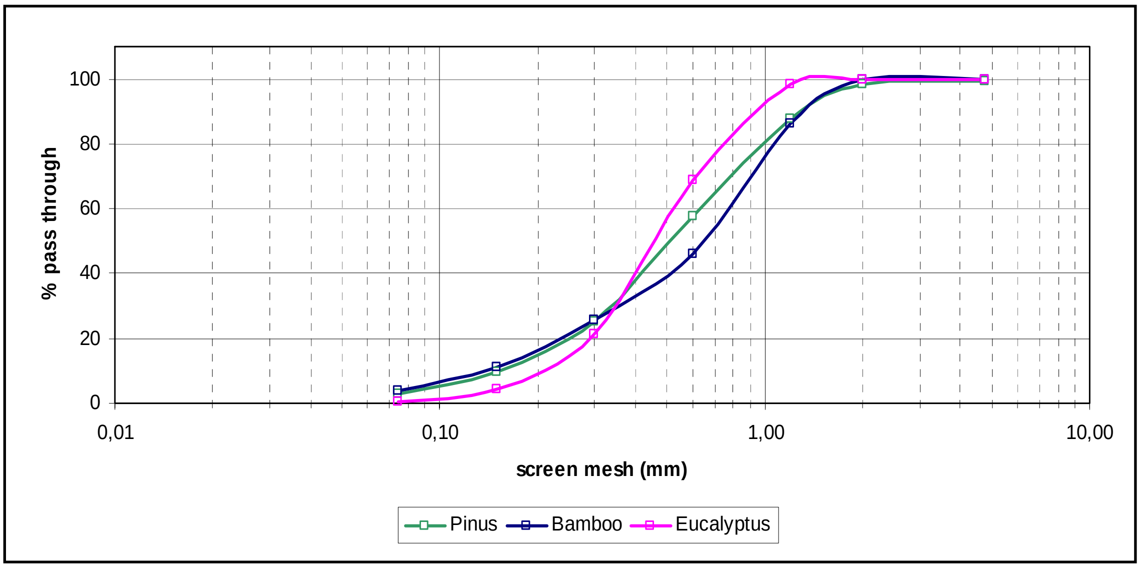

Figure 7 – Distribution curve

Hydration Curve

Hydration curve pattern for several parameters combinations was showed in Figures 8, 9 and 10, for composites from bamboo, eucalyptus and pinus particles, respectively. As expected cement type V paste shows a higher temperature peak and a smaller setting time when compared with cement type II paste. However particles types and theirs interaction with treatment types denotes different behavior of hydration curves.
Bamboo particles (Figure 8) were very inhibitory to both cement types. Despite the peak showed the cement type V combined with natural bamboo particles it can't be considered as a normal cement setting. Probably this peak is related to the C_3A reaction with bamboo compounds. None of the treatments applied to bamboo particles was sufficient to overcome inhibitory substances effects on cement setting.
Except for bamboo particles, calcium chloride at 3% was more efficient on composite performance. For the others particles a greater temperature peak was observed, mainly when catalyst was employed.

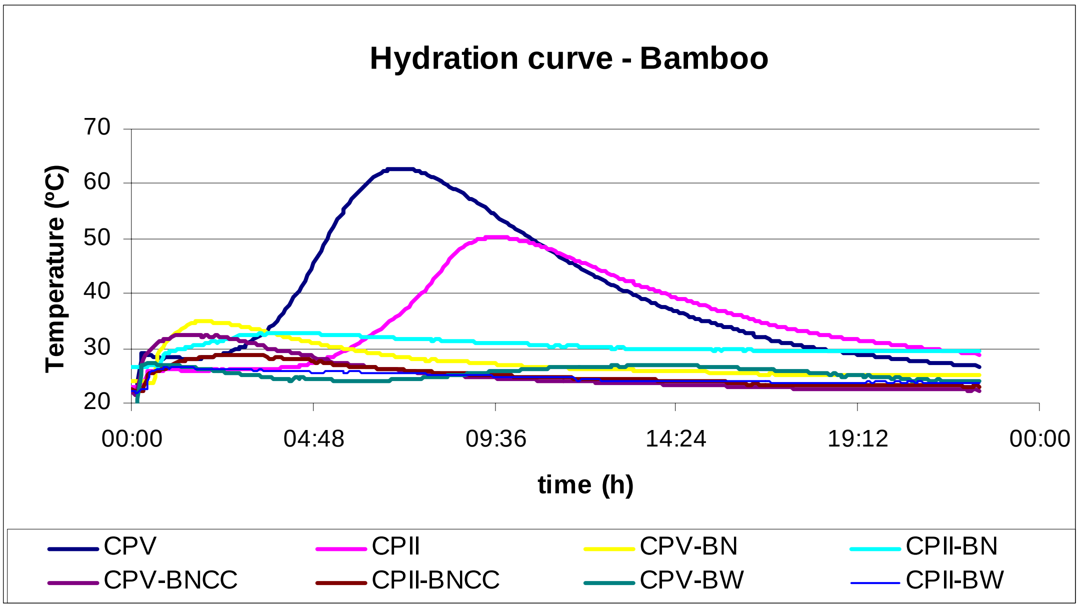

Figure 8– Composite hydration curve for bamboo particles.

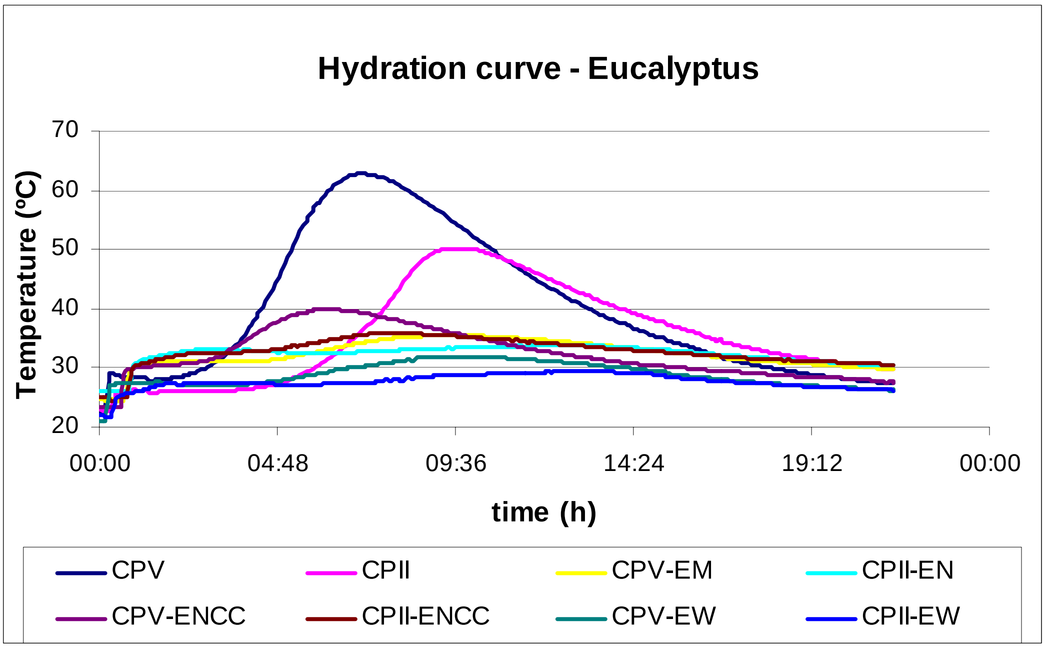

Figure 9- Composite hydration curve for eucalyptus particles.

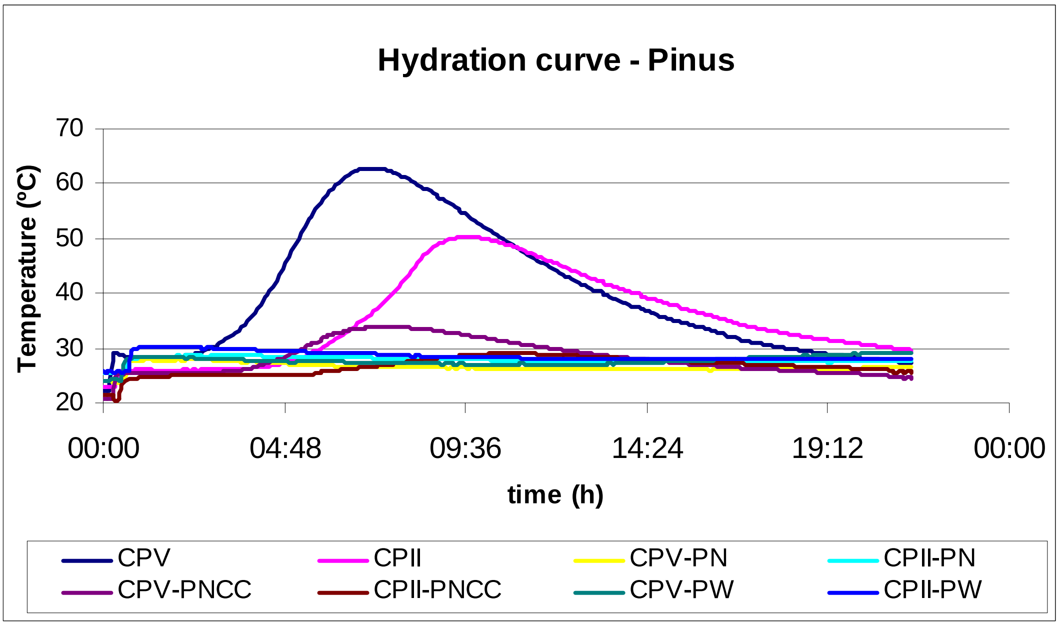

Figure 10 – Composite hydration curve for pinus particles.

UPV

Curve coefficients and maximum UPV were showed in Table 2. Ultrasonics was sensible enough to detect water to cement ratio influence on cement paste behavior. UPV coefficients indicate that calcium chloride addition enhances eucalyptus and pinus composites performance. However this treatment was less important than hot water extraction for bamboo particles.
Due to the porosity of the composites in most of the cases UPV strongly enhances at the first ages and seems to be stable at 7th days (Figures 9, 10 and 11).

Table 2 – Curve coefficients for the model: $v_t = v_{max}\{1\text{-}\exp(A+B.t)\}$

			Type V			Type II	
Treatments	Coefficients	v_{max}	A	B	v_{max}	A	B
Paste	w/c=0.3	3.71	-1.878	-0.555	3.82	-1.834	-0.424
Paste	w/c=0.7	2.90	-1.012	-0.626	2.83	-1.065	-0.312
	Nat	2.15	-0.788	-0.757	1.77	-0.884	-0.543
Eucalyptus	Nat + CC	2.30	-1.468	-0.737	2.05	-1.086	-0.594
	Washed	2.13	-1.613	-0.738	1.87	-1.332	-0.468
	Nat	1.67	-0.897	-0.513	1.22	-0.630	-0.374
Pinus	Nat + CC	1.66	-2.000	-0.349	1.53	-0.850	-0.397
	Washed	1.40	0.217	-0.811	0.80	0.440	-0.539
	Nat	1.25	-1.041	-0.358	0.91	1.076	-0.366
Bamboo	Nat + CC	1.26	-1.259	-0.123	1.26	-0.528	-0.249
	Washed	2.06	-0.880	-1.190	1.35	0.279	-0.682

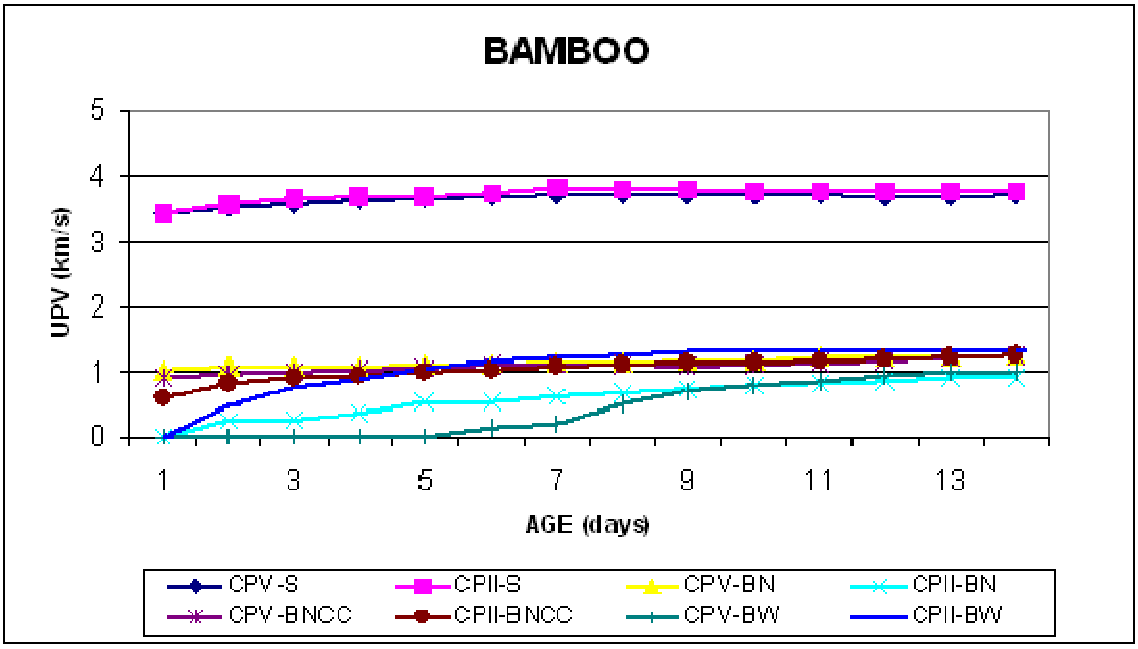

Figure 9 – UPV curve for bamboo particles composite.

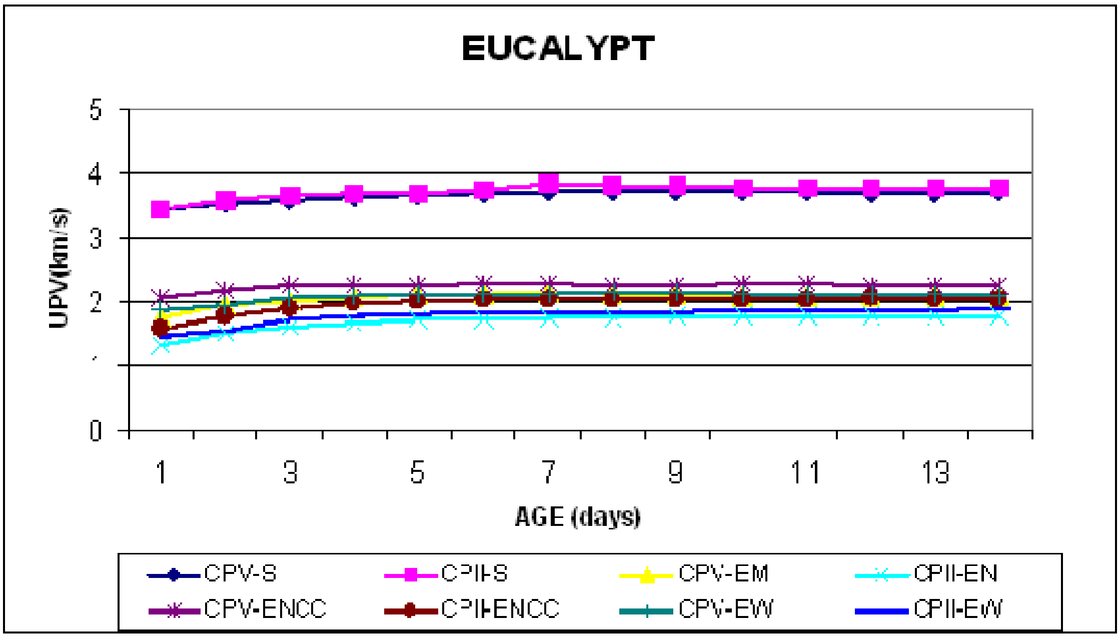

Figura 10 – UPV curve for eucalyptus particles composite.

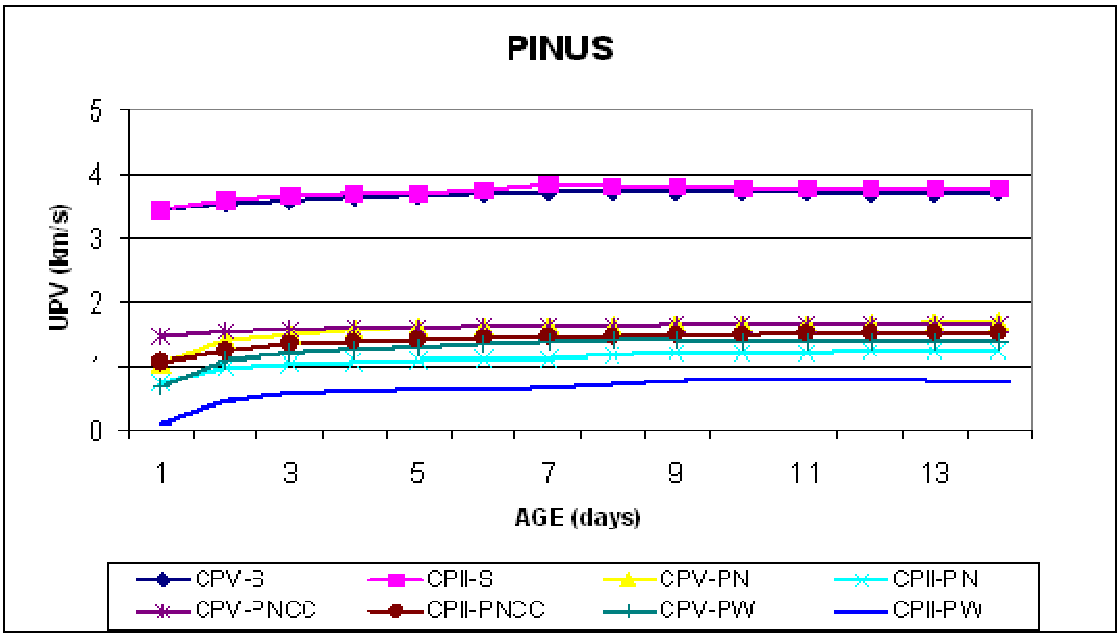

Figure 11 – UPV curve for pinus particles composite.

Strength at compression

The Table 3 presents composite compression strength.

Table 3 – Composite compression strength.

Particles	Treatment	Strength (MPa)	
		Cement	
Type		CP-V-ARI	CP-II-E-32
	a/c 0,33 (CP V)	31,24	-
	a/c 0,28 (CP II)	-	28,44
Bamboo	Natural (CP II BN e CP V BN)	1,63	0,63
	Hot water treatment (CP II BW e CP V BW)	13,93	8,63
	Calcium chloride at 3% (CP II BNCC e CP V BNCC)	1,67	1,28
Pinus	Natural (CP II PN e CP V PN)	8,33	3,40
	Hot water treatment (CP II PW e CP V PW)	4,60	1,23
	Calcium chloride at 3% (CP II PNCC e CP V PNCC)	9,10	6,28
Eucalyptus	Natural (CP II EN e CP V EN)	12,51	7,73
	Hot water treatment (CP II EW e CP V EW)	13,09	8,01
	Calcium chloride at 3% (CP II ENCC e CP V ENCC)	17,62	11,60

Statistical analysis

Tukey test LSD (Multiple Range Test) at 95% shows the cement type influence on composite average compression strength. Cement type V – a high initial strength cement (mean 9.17 MPa) was statistically different from cement type II – a blast furnace slag cement (mean 5.42 MPa).
Wood particles type was also an important parameter on composite compression strength. Values could be ranged from 11.80 MPa (Eucalyptus particles) to 4.63 MPa (Bamboo particles). Pinus particles show an intermediate value of 5.49 MPa.
Among the treatments applied to the wood particles, calcium chloride at 3% (mean 7.93 MPa) was the most efficient to overcome eucalyptus and pinus particles inhibition on cement setting. Composite compression strength for natural particles and washed particles were 5.71 MPa and 8.25 MPa, respectively.
However, the interaction between cement type, wood particles type and treatment applied to the wood particles pointed to the better combinations:

- Eucalyptus – cement type V and calcium chloride (mean 17.63 MPa);
- Pinus – cement type V and calcium chloride (mean 9.10 MPa);
- Bamboo – cement type V and hot washed particles (mean 13.93 MPa).

CONCLUSIONS

Among the investigated vegetable residues in this research work, bamboo particles were the most inhibitory to the setting of two Brazilian Portland cement types. Setting of the both cement types were less influenced by eucalyptus particles addition when compared with pinus particles. High initial strength cement (type V) was more efficient to overcome vegetable inhibitory effects than blast furnace slag cement Hydration curve and ultrasonic pulse velocity (UPV) results were in close agreement with respect to the interaction between vegetable particles, cement type and treatments applied to the vegetable particles.

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