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Destructive and non-destructive evaluation of bamboo chips - Portland cement composite

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Abstract: This paper reports the results of a study on evaluation of properties of a bamboo chips and Portland cement composite. Several treatments were carried out to reduce chemical incompatibility between Brazilian Portland cement (types II and V) and bamboo chips *(Bambusa tuldoides)*. Cylindrical specimens prepared with different mixtures were evaluated by compression tests as well as by a non-destructive evaluation. Results showed the influence of cement type, bamboo chip content and age of specimen on composite properties. Behaviour of the composites from Portland cement type V (high initial strength cement) was less influenced by the treatment applied to bamboo chips. Ultrasonic Pulse Velocity was sensitive enough to detect changes in the composite structure, mainly for specimens of lower ages and also for cement type and treatment applied to bamboo chips.

Key words: Bamboo chips, Portland cement, composite, chemical compatibility, non-destructive tests.

INTRODUCTION

Use of natural fibre as reinforcing material of composites is becoming popular all over the world (Agopyan *et al.*, 1990). Several factors such as low price, low energy consumption and low transport cost coupled with scarce availability of conventional materials, are mainly responsible for the search for alternative fibres.

The effect of fibre addition on matrix is related to the behaviour of both materials. Basically, there are three kinds of fibre-matrix reinforcement. The first one, known as fragile matrices, like paste, mortar and concrete, are reinforced by fibreglass, steel or asbestos. The second type of matrices are reinforced by fibres with low modulus of elasticity, like ordinary plastic and vegetable fibres. The last category, ductile matrices, like plastics and metals, are reinforced by fibres showing a high MOE (Agopyan, 1993).

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Generally, material performance is evaluated by means of destructive tests. However, in the recent years, progress has been made in the application of non-destructive tests (NDT) or non-destructive evaluation (NDE) to predict material structural changes. Several techniques can be applied for NDE on a specific material. Usually, ultrasonics is employed in steel and cement-based material evaluation, and is also applied in evaluating the setting and the hardening of wood cement composites (Beraldo and Rolim, 1996; Beraldo, 1999). The aim of this study was to evaluate the physical and mechanical properties of a Portland cement mortar modified by bamboo chip contents.

EXPERIMENTAL

Mature culms (5-year-old) of *Bambusa tuldoides* Munro were harvested at Campinas Agricultural Institute (Campinas, SP, Brazil). The culms were cut by means of an electric saw and the bamboo poles were air-dried for two weeks. Bamboo chips were produced in a hammer mill and chips of size smaller than 2.4 mm were selected.

Air-dried bamboo chips were soaked in 5 per cent sodium hydroxide solution for 6, 12 and 24 h, respectively. Then the chips were washed in water to eliminate alkaline residues (Azzini and Gondim-Tomaz, 1996).

Portland cement treatment

A commercial Portland cement type II, with blast furnace slag addition (NBR 11578, 1991), and a high initial strength Portland cement type V (NBR 5733, 1991), were used. Cement to sand ratio in the mortar was fixed at 1:3. Bamboo chip content was set 8, 16 and 24 per cent of cement mass respectively. The water to cement ratio was obtained by the mixture workability by employing a flow table device (NBR 7215, 1996). The ratios were kept at 0.60, 0.75 and 0.90, for 8, 16 and 24 per cent bamboo fibre contents, respectively. The various treatments and their combinations are shown in Table 1.

Three replications of cylindrical specimens (50 mm diameter and 100 mm height) were prepared with each compound combination (Table 1). Mixtures were placed in metallic moulds and then compacted by means of a metallic device. After 24 h, the samples were de-moulded and cured in a wet chamber for one week. Finally, the specimens were cured in the laboratory for 21 days (NBR 7215, 1996).

Evaluation of specimens

Specimens were weighed and soaked in water for 2, 6, 12, 24, 48, 72, 96 and 120 h. At the end of each period, the specimens were weighed again to calculate water absorption (NBR 9778, 1987).

After 3, 7 and 28 days of curing, specimens were carefully prepared according to the

Table 1. Various treatments and their combination applied to the bamboo chips

T 1	Type II mortar (reference)	T 14	Type II + 16% chips 2 h – boiling water
T 2	Type V mortar (reference)	T 15	Type V + 16% chips, 6 h – NaOH
T 3	Type II + 8% chips, 6 h – NaOH	T 16	Type V + 16% chips, 12 h – NaOH
T 4	Type II + 8% chips, 12 h – NaOH	T 17	Type V + 16% chips, 24 h – NaOH
T 5	Type II + 8% chips, 24 h – NaOH	T 18	TypeV + 16% chips, 2 h – boiling water
T 6	Type II + 8% chips 2 h – boiling water	T 19	Type II + 24% chips, 6 h – NaOH
T 7	Type V + 8% chips, 6 h – NaOH	T 20	Type II + 24% chips, 12 h – NaOH
T 8	Type V + 8% chips, 12 h – NaOH	T 21	Type II + 24% chips, 24 h – NaOH
T 9	Type V + 8% chips, 24 h – NaOH	T 22	Type II + 24% chips, 2 h – boiling water
T 10	Type V + 8% chips, 2 h – boiling water	T 23	Type V+24% chips, 6 h – NaOH
T 11	Type II + 16% chips 6 h – NaOH	T 24	Type V + 24% chips, 12 h – NaOH
T 12	Type II + 16% chips 12 h – NaOH	T 25	Type V + 24% chips, 24 h – NaOH
T 13	Type II + 16% chips 24 h – NaOH	T 26	Type V + 24% chips, 2 h – boiling water

Brazilian Standards and subjected to an axial compression test (NBR 7215, 1996). Splitting test (NBR 7222, 1994) was also conducted on specimens cured for 28 days.

Ultrasonic pulse velocity (UPV)

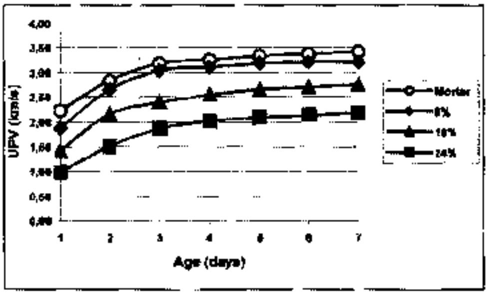
To evaluate the ultrasonic pulse velocity (UPV) across the specimens, an ultrasonic tester device, model BP-7 (Steinkamp - Germany) was employed. Two transducers of 45 kHz of resonance frequency, having an exponential section, were positioned at the base of the specimens. UPV (km/sec) was obtained by dividing the samples height (mm) by the propagation time (microseconds). During the first week, UPV was obtained daily, aiming to evaluate the changes in the composite structure generated by matrix hardening. At 28 days, UPV was also measured to verify its possible correlation with the composite compression strength.

Statistical analysis

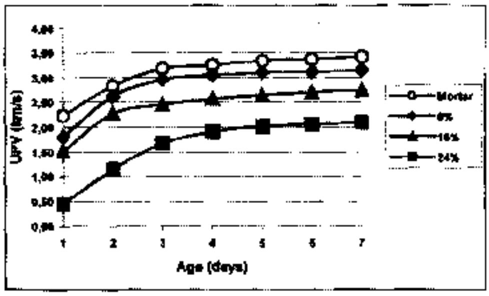
Data were analysed and compared (Tukey´s test) by employing a statistics software, Statsgraphics 4.1. The influence of each factor was compared through ANOVA. A model and a Multiple Range Test were proposed to verify the best combination of these factors.

RESULTS AND DISCUSSION

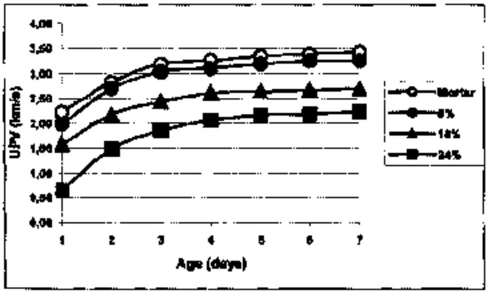
Figures 1 and 2 show the relationship between UPV and the specimen age. A significant increase in the UPV values was observed during the first week, which was generated by the cement setting and hardening. UPV seemed to stabilize after 7 days. Subsequent changes in the composite macrostructure were not easily detected by the ultrasonic technique, probably because of water evaporation and cessation of cement compounds hydration. It is also possible that the new hydration products had not contributed significantly to modify the composite structure. UPV was sensitive enough to detect



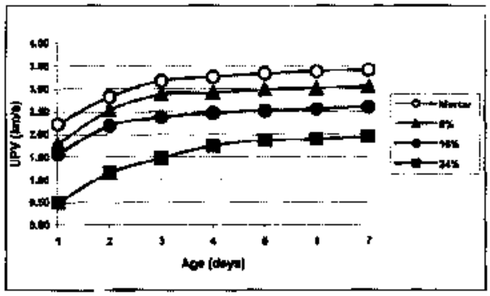
Immersion in NaOH – 6h



Immersion in NaOH – 12 h

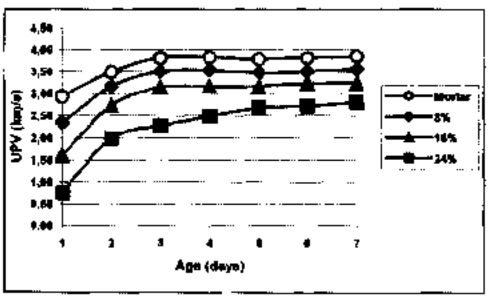


Immersion in NaOH - 24 h

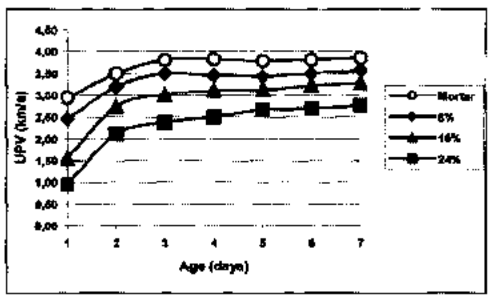


Immersion in boiling water – 2 h

Figure 1. Ultrasonic pulse velocity *vs* age of cement type II composites for the treatments applied to bamboo chips.



Immersion in NaOH – 6h



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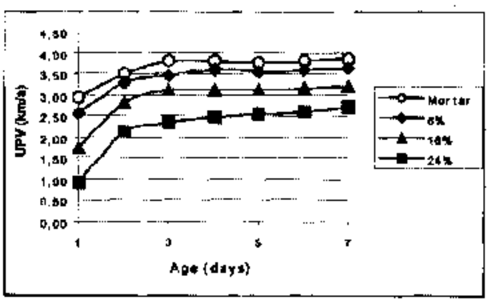
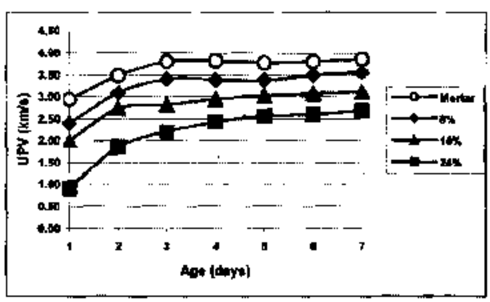


Immersion in NaOH - 24 h



Immersion in boiling water – 2 h

Figure 2. Ultrasonic pulse velocity *vs* age of cement type V composites for the treatments applied to bamboo chips.

treatment effects mainly when they are compared with mortar references (without fibres), but for some treatments, mainly for those corresponding to 8 per cent bamboo chip content. UPV results were very close to the reference mortars (for both cement types).

Higher chip content in the specimen led to smaller UPV and also more discontinuities in the composite structure, preventing an adequate UPV propagation, because energy dissipation increased.

Water absorption

Figures 3 and 4 present the water absorption (WA) by the bamboo chips composites based on cement types II and V, respectively. After 2 h, WA was not appreciable with time because of the hygroscopic properties of the composites. WA ranged from 4.73 per cent (for cement type II + 8% bamboo chips treated in boiling water) to 10.83 per cent (for cement type V + 8% bamboo chips treated for 24 h in sodium hydroxide solution). Due to its low sensitivity to the action of the bamboo extractives, the composites from cement type V showed a smaller WA than those from cement type II. All the composites based on bamboo chips treated in boiling water presented smaller WA when compared with those of alkaline treatments. Probably, alkaline solutions caused higher degeneration in bamboo chips, mainly for the composites with high content of chips.

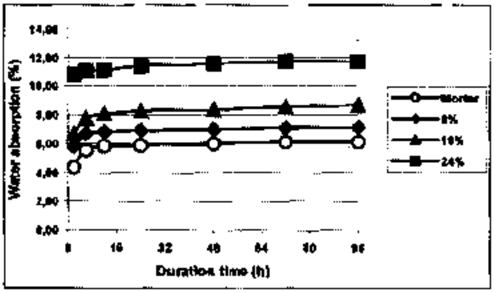
Compression strength

Tables 2 and 3 show the results of the compression strength of the type II and type V Portland cement composites, respectively. As expected from the preliminary analysis of the UPV and WA, none of the composites reached the compression strength of the mortar reference (without bamboo chips). In most cases, type V cement-based composites were superior to those from the cement type II.

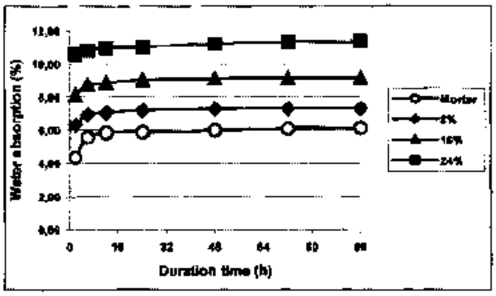
For both cement types, composite compression strength was affected by bamboo chip content and specimen age. As in any other cement-based materials, the composite compression strength increased with the age of the specimens. The treatment type applied to the bamboo chips (boiling in water or immersion in sodium hydroxide solution) did not affect the compression strength.

Tukey´s test – Honestly significant difference (HSD) for compression strength

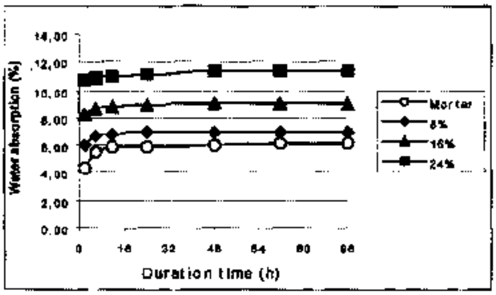
For Portland cement type II and type V composites, the comparison between the average differences, with respect to chip content, specimen age and the treatment applied was made. For cement type V, the effect of the treatment applied to the bamboo chips was not significant. For both the cement types, it was possible to range the results with respect to chip content and specimen age. For chip content, the results



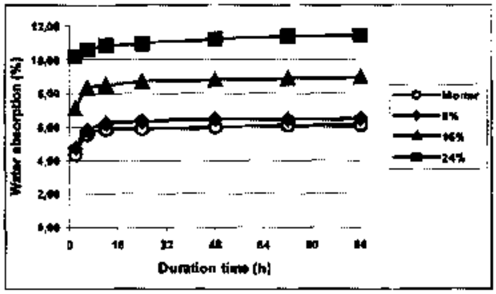
Immersion in NaOH – 6h



Immersion in NaOH – 12 h

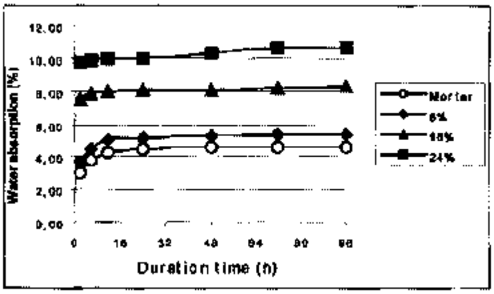


Immersion in NaOH - 24 h

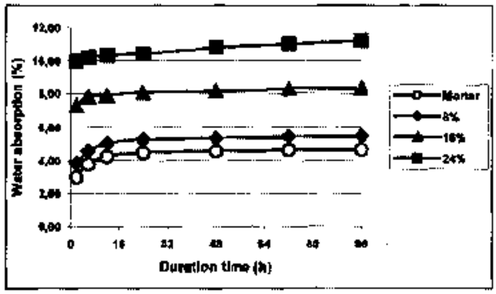


Immersion in boiling water – 2 h

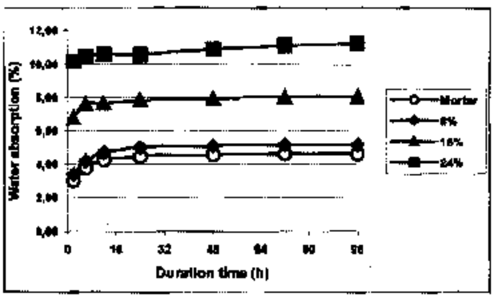
Figure 3. Water absorption *vs* immersion time, for cement type II composites for the treatments applied to bamboo chips.



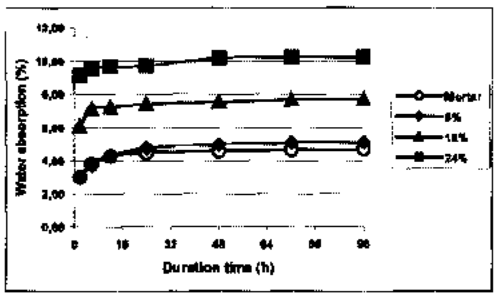
Immersion in NaOH – 6 h



Immersion in NaOH – 12 h



Immersion in NaOH - 24 h



Immersion in boiling water – 2 h

Figure 4. Water absorption *vs* immersion time, for cement type V composites for the treatments applied to bamboo chips.

Table 2. Compression strength for cement type II composites

	Chip content	8%					16%				24%		
Age		T1	T3	T4	T5	T6	T11	T12	T13	T14	T19	T20	T21	T22
	CS	*	7,31	7,80	9,46	10,76	5,25	6,07	6,79	6.50	3,14	4.21	3,80	2,60
3 d	SD	*	0,18	0,67	0,99	0,42	0,33	0,22	0,23	1.05	0,23	0,30	0,21	0.06
	CV	*	2.46	8.59	10,47	3,90	6,29	3,62	3,39	16,15	7,32	7,13	5,53	2,31
	CS	15.08	10,24	7,94	12,64	14,36	7,79	9.57	7,84	9,72	5,31	5,42	4,69	4.46
7 d	SD	4,40	1,33	0,56	0,54	0,75	0.27	0,59	0,99	0,87	0,03	0,22	0,28	0.61
	CV	2918	12,99	7,05	4,27	5,22	3,47	6,17	12,63	8,95	0,56	4,06	5,97	13.68
	CS	24,7[a]	15,9[b]	18,0[b]	18,5[b]	16,9[b]	9,4[c]	10,3[c]	11,3[c]	10,6[c]	6,2[d]	6,6[d]	6,1[d]	6,3[d]
28 d	SD	2,25	0,71	0,23	1,33	0,72	0.65	0,55	1,32	1,30	0,54	1,11	0,61	0,54
	CV	9,09	4,45	1,28	7,18	4,26	6,89	5,34	11,71	12.29	8,70	16,79	9,95	8,61

CS: compression strength (MPa); SD: standard deviation (MPa); CV: coefficient of variation (%). Means with the same letter are not significantly different at ($P < 0.05$) (Tukey's test). *Specimens damaged.

Table 3. Compression strength for cement type V composites

	Chip content	8%					16%				24%		
Age		T2	T7	T8	T9	T10	T15	T16	T17	T18	T23	T24	T25	T26
	CS	*	13,15	11,23	16,59	16,27	8,63	6.92	8,28	7,56	3.62	3,43	3,73	3,28
3 d	SD	*	1.07	0.78	0,76	1,02	0.38	0,68	1,64	0,86	0,25	0,11	0,45	0,23
	CV	*	8,14	6,95	4,58	6,27	4.40	9,83	19,81	11,38	6,91	3,21	12,06	7,01
	CS	24,71	17,33	17,64	17,00	16,61	11,26	9,57	10,58	10,26	4,39	4,43	4,80	4.56
7 d	SD	5,91	1,72	2,12	3,05	4,60	1,10	0,23	0,72	1,50	0,35	0,29	0,34	0,40
	CV	23,92	9,92	12,02	17,94	27,69	9,77	2,40	6,80	14,62	7,97	6,55	7,08	8,77
	CS	33,5[a]	20,7[b]	22,8[b]	19,5[b]	19,0[b]	12,6[c]	11,7[c]	12,3[c]	12,6[c]	6,1[d]	6,5[d]	6,3[d]	6,8[d]
28 d	SD	7,72	1,06	2,15	3,83	5,13	1,72	0,06	0,43	0,75	0,79	1,18	0,89	0.55
	CV	23,06	5,11	9,43	19,62	26,99	13,62	0,51	3,50	5,97	12,87	18,27	14,08	8,10

CS: axial compression (MPa); SD: standard deviation (MPa); CV: coefficient of variation (%). Means with the same letter are not significantly different ($P < 0.05$) (Tukey's test). *Specimens damaged.

ranged in the order of 8 > 16 > 24%; for composite age, 28 days > 7 days > 3 days. The Tukey's HSD test applied to cement type II composites showed a non-significant difference between the treatments. So, for the conditions employed in this study, the choice of a treatment type must consider the cost of boiling bamboo chips or the employment of an alkaline treatment for 6 h (sodium hydroxide at 5% concentration). For the latter, the cost necessary to neutralize the waste solution or to forward it to reprocessing should also be considered.

Multiple regression analysis for compression strength

Equations 1 and 2 present the models proposed for the composite compression strength, for cement types II and V, respectively. However, the cement type V, the factors are not statistically significant.

Type II: $CS = 2.39 + 6.19*age + 0.44*treat - 1.83*age*chip\ content$ (1)

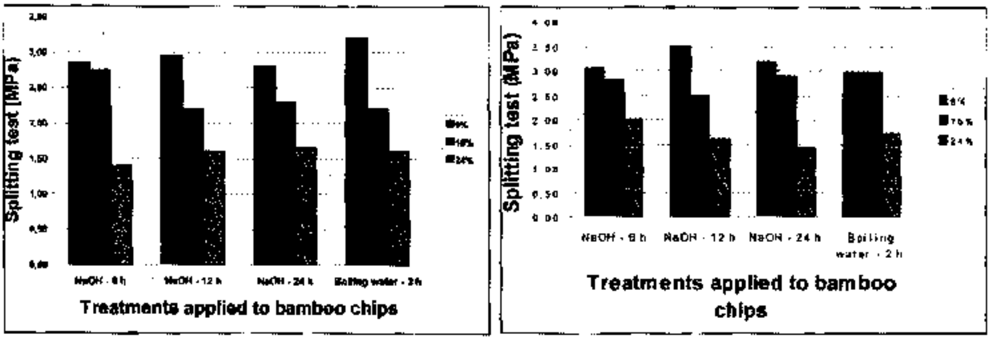
Type V: $CS = 15.47 + 3.90*age - 4.61*chip\ content - 0.82*age*chip\ content$ (2)

Splitting test

Results of the splitting test applied to the specimens aged 28 days are presented in Figures 5A and 5B, for cement types II and V, respectively. The same trend was observed when the results were compared with UPV, WA and compression strength. Fibre to matrix adherence was more evident for 8 per cent bamboo chip content, mainly when the chips were previously treated in boiling water. For this combination, the best results were 3.20 MPa and 5.70 MPa for cement types II and V, respectively. On the other hand, reference mortars were 3.63 MPa and 4.48 MPa, for cement types II and V, respectively.

Global analysis

Tukey's test at 5% significant level permits to select the best combination for each



(A) Cement type II (B) Cement type V

Figure 5. Tensile splitting average for specimens 28 days aged.

Table 4. Best combination for cement types II and V (Tukey's test at 5% significant level)

Evaluation	Cement type II	Cement type V
NDE (UPV)	T5	T9 = T7 = T8 = T18 = T10
	T3 = T13 = T6	T15 = T17 = T16
Water absorption	T6	T10
	T3 = T5	T9
Compression strength	T6 = T4 = T5	T9 = T10 = T8 = T7
	T3	T15 = T17 = T18 = T16
Splitting test	T6	T10
	T4 = T5 = T3	T8 = T9 = T7 = T18

cement type (Table 4). Among the combinations, the bamboo chips boiled in water and those chips treated after 24 h in sodium hydroxide solution were the most appropriate for cement type II (treatments T6 and T10) and cement type V (treatments T5 and T9), respectively. However, for an industrial application, the duration of alkaline treatment may be reduced to 6 h, as explained by the results obtained for the combinations T3 (for cement type II) and T7 (for cement type V).

Correlation between UPV and composite compression strength

NDE by ultrasonic pulse velocity (UPV or *v*) was sensitive enough to estimate the compression strength (CS) of the specimens, showing a higher regression coefficient. Mathematical models proposed were similar to cement-based materials as reported by (Neville, 1982).

For cement type II: $CS=1.4161*v^{1.9045}$ $r^2 = 0.94$ (3)

For cement type V: $CS=0.0517*v^{4.558}$ $r^2 = 0.99$ (4)

CONCLUSIONS

Properties of bamboo chips and Portland cement (types II and V) composites were strongly dependent on the cement type and the chip contents and, to a certain extent, on the treatment applied to the bamboo chips. Cement type V composites performed better than those from cement type II. The bamboo chip content was the main factor responsible for changes in composite properties. Smaller chip content must be considered in further evaluations, looking to optimize this factor in the composite properties. The treatment types applied to the bamboo chips were statistically significant only for cement type II composite behaviour. UPV method was sensitive enough to detect the micro-structural changes in the composites, mainly at early stages of curing. After 7 days, UPV tended to stabilize and there was no significant difference for longer curing period. A mathematical model is proposed to predict compression strength as a function of UPV.

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