Acta Scientiarum. Technology
ISSN: 1806-2563
eduem@uem.br
Universidade Estadual de Maringá
Brasil

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Acta Scientiarum. Technology, vol. 34, núm. 3, julio-septiembre, 2012, pp. 269-276
Universidade Estadual de Maringá
Maringá, Brasil

Acta Scientiarum

http://www.uem.br/acta
ISSN printed: 1679-9275
ISSN on-line: 1807-8621
Doi: 10.4025/actascitechnol.v34i3.14372

Masonry concrete block strength compound with sawdust according to residue treatment

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ABSTRACT. The behavior of building blocks with the partial replacement of fine aggregates by sawdust is evaluated. The parameter adopted comprised analysis of the compressive strength according to the treatment applied to sawdust residue of the species *Dinizia Excelsa Ducke* (red angelim). Blocks were composed by replacing fine aggregates by sawdust at 5% weight. Before mixing the wood residues to the concrete, the former underwent treatment so that wood residues could be compatible with the cement matrix. Two treatment processes were investigated. The first treatment comprised the washing of residues in an alkaline solution (lime) at a 5% proportion (weight / weight). The second treatment comprised the immersion of the residue in aluminum sulfate. Analysis was undertaken from compressive strength assays of the blocks on the 7th and 28th day. Results showed low efficiency in the alkaline-based treatment (lime) and good performance in the aluminum sulfate-based treatment. The production of masonry blocks with a replacement of 5% fine aggregates for this type of treatment and species studied is possible.

Keywords: composite, cement-wood, masonry blocks.

Resistência de blocos de concreto para alvenaria compostos com pó de serra em função do tratamento adotado no resíduo

RESUMO. O objetivo deste trabalho foi avaliar o comportamento de blocos para a alvenaria de vedação com substituição parcial de agregado miúdo por pó de serra. Para tal finalidade, adotou-se como parâmetro a análise da resistência à compressão em função do tratamento aplicado ao resíduo de serragem. O resíduo utilizado no estudo foi da espécie *Dinizia Excelsa Ducke* (Angelim Vermelho). Os blocos foram confeccionados a partir de uma dosagem, que substitui 5% em massa o agregado miúdo pela serragem. Antes de misturar o resíduo ao concreto, este passou por um tratamento para compatibilizar o resíduo com a matriz cimentante. Foram estudados dois processos de tratamento. O primeiro consistiu na lavagem dos resíduos em solução alcalina (cal) na proporção de 5% (peso/peso). O segundo foi à imersão do resíduo em sulfato de alumínio. A análise foi feita a partir de ensaios de resistência à compressão dos blocos aos 7 e 28 dias. Os resultados mostraram baixa eficiência do tratamento à base de solução alcalina (cal) e bom desempenho do tratamento a base de sulfato de alumínio; e que é possível a produção de blocos de vedação com substituição de 5% do agregado miúdo para este tipo de tratamento e espécie estudada.

Palavras-chave: compósito, cimento-madeira, blocos de vedação.

Introduction

In recent years civil construction industry has taken on an environmental responsibility stance coupled to the social role it previously adopted. Owing to the fact that the construction industry is a productive sector, it generates environmental impacts through the extraction and use of prime matter, the production of building materials, the construction process, the generation of debris, and even by not recycling and by discarding residues. This situation is due to the sector's cultural condition and to the lack of planning and skilled labor. On the other hand, the construction industry is capable of reusing residues and is currently a major recycler of residues from other industrial sectors. This is due to the features of many residues as secondary material which may be applied in civil construction within a comprehensive manner through the partial or total replacement of prime matter used as standard input.

Viable alternatives to reuse residues without being simultaneously polluting agents should be found. The Amazon timber industry generates a large amount of residues which are directly stored in the environment or burned, with enormous environmental problems. Therefore, current study focuses on the production of material made from a cement matrix and strengthened by timber residues from the Amazon region. However, the use of some plant fibers may be restricted because of their high amounts of sugar. When timber gets in contact with water, sugar is released. Compounds that interfere in the process of the binder's hydration reaction, such as acids, phenols, resins, tannins and salts are also frequently released.

According to (WEI et al., 2000a and b; JORGE et al., 2004; PAPADOPOULOS, 2007; CHEUMANI et al., 2011; PEREIRA et al., 2012) sugar found in plants is released when the vegetal fiber comes in contact with the water of cement hydration during the formation of the composite. The release of sugar compounds eventually interferes in the binders' hydration and a decrease of their reaction rate occurs. Consequently, cement curing (hardening) time is slowed and curing time increased. However, the difficulty in removing sugar compounds from the fiber may impair their use. Other substances in the structure of plant tissues, such as phenols and acids, may delay and, in some cases, prevent cement hardening time. The use of some timber compatibility process with the cement matrix may be thus required to have the lowest possible influence in the process of cement hydration.

A few studies focusing on the feasibility of the production of the composite cement-wood with species of Amazon region, have been carried out (MACÊDO et al., 2011). Since results were satisfactory for certain species, the feasibility of producing building components based on the wood-cement mixture was tested. Current research assessed the above-mentioned composite material through the manufacture and compressive strength tests to masonry blocks sing residual wood from Dinizia excelsa Ducke (red angelim), with two different treatments, in partial replacement of fine aggregates.

Material and methods

Materials

Mineral binder

The mineral binder in the experiment was classified as high initial strength Portland cement CPV-ARI, according to NBR 5733 (ABNT, 1991). Table 1 shows the characteristics of the cement used in the testing. Cement type was employed because to allow faster demolding owing high strength during the first days, to its wide usage in the precast industry and to its better tolerance to plant particles (MACÊDO et al., 2011).

Residue

Wood residues of Dinizia excelsa Ducke (red angelim), widely used by the local furniture industry, was produced by the timber industry in the metropolitan region of Belém, Pará State, Brazil. The sawdust was collected in plastic bags and oven-dried for 24 hours at 90°C and subsequently classified according to the size of its particles and sieved in mesh # 4.8. The material was characterized as fine sawdust (Table 2).

Sand

The sand used in the testing consisted of river bed quartz extracted from ore mines in Ourém, Pará State, Brazil. Sand was characterized by granulometric composition tests, characteristic maximum size (CMS), fineness, specific gravity, unit mass and swelling coefficient, according to ABNT standards (Table 3).

Table 1. Characteristics of high initial strength Portland cement CP V-ARI.

Chemical assays				
Tests	NBR	Unit	Results	NBR 5733/91 Specification
Loss by Fire – LF	5743/89	%	3.21	≤ 4.5
Magnesium Oxide – MgO	9203/85	%	2.88	≤ 6.5
Sulfuric anhydride – SO_3	5745/89	%	3.60	≤ 3.5
Insoluble residue	8347/92	%	1.22	≤ 1.0
Equivalent alkalis in Na_2O (0.658 x K2O% + Na_2O%)	-	%	0.88	Not applicable
Free Calcium Oxide – CaO	7227/90	%	1.44	Not applicable
Physical and mechanical assays				
Tests	NBR	Unit	Results	NBR 5733/91 Specification
Specific Area (Blaine)	7224/96	m^2 Kg^{-1}	4.950	≥ 3000
Specific Gravity	6474/84	g cm^{-3}	3.11	Not applicable
Density	-	g cm^{-3}	1.07	Not applicable
Fineness - Residue by 0.075mm sieve (#200)	11579/91	%	0.42	≤ 6
Fineness - Residue by 0.044mm sieve (#325)	11579/91	%	2.62	Not applicable
Water of normal consistency paste	11580/91	min.	31.1	Not applicable
Start of hardening time	11581/91	min.	133	≥ 60
End of hardening time	11581/91	min.	201	≤ 720
Hot expandability	11582/91	mm	0	≤ 5.0

Compressive strength					
Age (days)	Min.	Max	Average	Deviation	NBR 5733/91 Specification
1	22.1	30.1	26.1	2.08	≥ 14.0
3	31.6	37.6	34.8	1.46	≥ 24.0
7	34.1	41.4	38.3	1.69	≥ 34.0
28	42.7	50.4	45.0	1.34	Not applicable

Table 2. Characteristics of residues – Sawdust.

Determinations	Testing method	Results		
		Sieve mesh	Retained material	
Particle size composition NBR7217 (ABNT, 1987a)	NBR 7217 (ABNT, 1987a)	ABNT (mm)	Individual	Accum.
		4.8	0	0
Mass unit: dry and loose	NBR 7251(ABNT, 1982c)		0.253Kg dm^{-3}	
Mass unit: dry and compacted	NBR 7251(ABNT, 1982c)		0.285Kg dm^{-3}	

Table 3. Characterization of the fine aggregate – Sand.

Determinations	Testing method	Results		
		Sieve mesh	Retained material	
		ABNT (mm)	Individual (g)	Accum. (%)
Particle size composition NBR 7217 (ABNT, 1987a)	NBR 7217 (ABNT, 1987a)	4.8	0	0.00
		2.4	30	0.30
		1.2	190	2.00
		0.6	7810	80.00
		0.3	1330	94.00
		0.15	500	99.00
		Fundo	140	100.00
CMS	NBR 7217 (ABNT, 1987a)		2.4 mm	
Fineness	NBR 7217 (ABNT, 1987a)		1.91	
Specific gravity	NBR 9776 (ABNT, 1987b)		2.64 kg dm^{-3}	
Unit mass	NBR 7251 (ABNT, 1982c)		1.560 kg dm^{-3}	
Swelling coefficient	NBR 6467 (ABNT, 1987c)		1.40	
Organic impurities	NBR 7220 (ABNT, 1987d)		> 300 p.p.m	

Table 4. Characterization of the coarse aggregate – Pebbles.

Determinations	Testing method	Results		
		Sieve mesh	Retained material	
		ABNT (mm)	Individual (g)	Accum. (%)
Particle size composition NBR 7217(ABNT, 1987a)	NBR 7217 (ABNT, 1987a)	25	0	0
		19	0	0
		12	112	1.00
		9	1247	14.00
		4.8	5407	68.00
		2.4	0	68.00
		total	10.000	100.00
Fineness	NBR7217 (ABNT,1987a)		7.07	
Specific gravity	NBR9776 (ABNT, 1987b)		2.63 kg dm^{-3}	
Mass unit	NBR7251 (ABNT, 1982c)		1.55 kg dm^{-3}	
Dmax	NBR7217 (ABNT, 1987a)		19 mm	
Abrasion	NBR 6465 (ABNT, 1987f)		58.91%	

Pebbles

Round pebbles were used as a coarse aggregate since they are the commonest material employed in the region for the production of concrete. The quartz was extracted from a field in the northeastern region of the state of Pará, Brazil. Pebbles were dried and characterized by granulometric composition tests, CMS, Los Angeles abrasion resistance, specific density and mass unit, according to ABNT standards (Table 4).

Experimental program

Reference mark dosage analysis

Dosage analysis is mandatory to select the material available in the region for the production of concrete blocks. Consequently, the best ranges of particle size compositions, coarse-fine aggregate ratios and binder-aggregate ratio were investigated in current tests.

Dosage analysis, based on the ABCP method (FERREIRA JÚNIOR, 1995), aimed at finding the best ratio between fine and coarse aggregates through the highest compactness possible. Ratio ranges between aggregates (20/80, 25/75, 30/70, 35/65, 50/50 and 60/40) were defined and compactness was evaluated by the mass unit obtained from the mixture and its density achieved by metal socket. Aggregates were pre-mixed and placed in a metal container of known volume, with the edge fitted with a wooden frame for the settling of material. After the compacting of the mixture, mass values were determined and an optimum compactness curve was found (Figure 1).

The graph defined the reference mark with the best performance in mass unit proportion among aggregates; or rather, the 50/50 ratio which had the greater mass. Reference was consequently defined. Table 5 shows the elaboration of 4 proportions, two of which would be richer in binder, according to studies for precast blocks (ALVES, 2004). The ratio binder: aggregate and moisture content were subsequently analyzed. Results showed the behavior of the mixture with regard to molding consistency and to subsequent compressive strength.

Table 4. Characterization of the coarse aggregate – Pebbles.

Determinations	Testing Method	Results		
		Sieve mesh	Retained material	
		ABNT (mm)	Individual (g)	Accum. (%)
Particle size composition NBR 7217(ABNT, 1987a)	NBR 7217 (ABNT, 1987a)	25	0	0
		19	0	0
		12	112	1.00
		9	1247	14.00
		4.8	5407	68.00
		2.4	0	68.00
		total	10.000	100.00
Fineness	NBR7217 (ABNT,1987a)	7.07		
Specific gravity	NBR9776 (ABNT, 1987b)	2.63 kg dm^{-3}		
Mass unit	NBR7251 (ABNT, 1982c)	1.55 kg dm^{-3}		
Dmax	NBR7217 (ABNT, 1987a)	19 mm		
Abrasion	NBR 6465 (ABNT, 1987f)	58.91%		

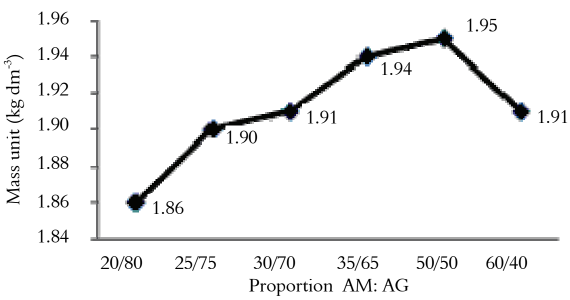

Figure 1. Mixture Proportion.

Table 5. Defining molding reference.

Mixtures	1:5	1:7	1:8	1:10
Unit mixture	1: 2.5 : 2.5	1: 3.5 : 3.5	1: 4 : 4	1: 5 : 5
Water/cement	0.40	0.50	0.60	0.7

The best proportion of materials for the production of blocks was determined and the best reference mark to replace 5% sand by sawdust was defined after the analysis of compressive strength.

As a parameter for initial evaluation, mixture consistency was analyzed according to the exact point in pellet formation, characteristic of dry concrete. Mixture compactness was obtained according to the equipment adopted for concrete block production or vibrating press.

Water rate is an extremely important factor that should be analyzed meticulously in dry consistency concrete blocks. The ideal percentage of water varies between 4 and 7% of the mass of dry materials. However, in 1:5 and 1:7 reference marks, segregation of material at molding and compactness in the machine and non-formation of pellets occurred. Consistency, which is directly related to the amount of water used in these reference marks, failed to be satisfactory.

The above facts are related to the characteristics of materials used in current test and which differ from materials usually employed in other regions of Brazil. Consequently, the same water rate should not be employed. Pebbles are highly brittle, or rather, there is up to 30% sand in their composition. Further, the sands of the state of Pará, Brazil, characterized by uniformity and high fineness, require a slightly higher amount of water. The interval proposed demanded an increase close to 0.5% in water rate and thus a moisture rate between 6.5 and 7.5%. Since the initial investigation of reference marks 1:5 and 1:7 was modified (Table 6), a more uniform and more cohesive concrete was obtained, with more homogeneity and better consistency due to pellet formation (Figure 2).

Table 6. Definition of molding reference marks.

Mixtures	1:5	1:7	1:8	1:10
Unit mixture	1: 2.5 : 2.5	1: 3.5 : 3.5	1: 4 : 4	1: 5 : 5
Water/cement	0.45	0.55	0.60	0.7

Figure 2. Dry consistency: zero decrease.

Whereas a horizontal-axis cement mixer was used for concrete mixing, a semi-automatic vibrating press was used for block molding. The amount of time taken for mixing the material in the mixer and maximum vibrating compression time were evaluated so that the de-molding of the concrete would not occur, while cracks in the sides of the blocks and the segregation of material during compression would be avoided. The amount of time required usually depended on the type of equipment used in molding and on synchronization of block-production team (mixing and molding). Maximum of

3 minutes for the mixture and 2 minutes for vibration-compaction was determined for current study.

A set of three blocks was produced for each molding and then stored for initial curing. The blocks were transported on supporting pallets to an open space protected from direct sunlight. Two hours after molding, the curing process started. Curing lasted 24 hours during which the blocks were covered with a moist blanket and water sprayed every 2 hours. On the third day the batch was taken to the laboratory of materials, coated for surface regularization and tested for compressive strength in an ASMLER universal machine (1000 kN), following NBR 7184 (ABNT, 1992). Test results must meet the NBR7173 (ABNT, 1982b) standards which determine minimum compressive strength of 2.0 MPa for the individual block and an average 2.5 MPa so that the blocks may be used in buildings.

Figure 3. Compressive strength test.

The best performance reference mark for block formation and for the replacement of 5% sand by wood residues was selected from the results of the compressive strength test. Figure 4 shows the test results for reference blocks.

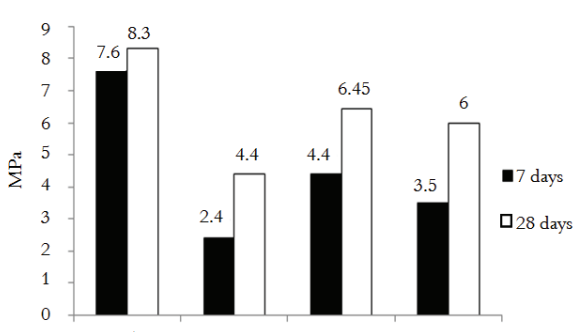

Figure 4. Compressive strength of reference blocks according to reference mark.

According to the above, ratios 1:5 and 1:8 had the best resistance results. Therefore, 1:8 rate was selected which, on average, reached 6.45 MPa on the 28th day. The selection was also due to more economical cement amounts.

Treatment of wood residue

Wood residues were collected and dried in an oven for 24 hours at controlled temperature not higher than 90°C to prevent any fiber degradation. Since drying reduced water amount and eventually decreased portions of extracts in the residues' cell lumens, all excessive moisture was removed from the material and a point of equilibrium reached. After drying, the material was sieved with a # 4.8 sieve for a uniform sawdust format. After sieving, the residues underwent two types of treatment. The first treatment consisted of washing the sawdust in an alkaline solution. The second treatment comprised washing in an aluminum sulfate solution, following (MACÊDO et al., 2011). The best results in compressive strength rates of the composite (cement and sawdust) were chosen by the processes above.

The amount of lime used for immersion in alkaline solution was 5% w/w (weight / weight) of unit mass of sawdust, diluted in 10 liters of water for 1 kg of dry sawdust. Hydrated lime, type III-CH, commonly used in painting, was used. The sawdust was immersed in water for 24 hours, washed in running water and dried in the shade for three days. However, the residues were still very moist after this period and a few more days for drying were needed. The sawdust was kept in the shade and between 7 to 10 days were required to have a moisture rate suitable for the manufacture of concrete blocks. According to molding tests, the residues' best moisture rate had to be close to 30% for a satisfactory consistency of the concrete. Immersion of the sawdust in sulfate solution occurred similarly to that in the alkaline solution and the product's concentration was 150 gram per liter. Figure 5 shows water after the release of extracts.

Figure 5. Released extracts after a 24-hour immersion.

Molding of blocks with sawdust

When dry (before treatment) and wet (after treatment) mass were compared, the residue had an approximately 30% moisture rate at the time of mixing the wood residue to the concrete. The placing of the still wet residue in the mixture was an asset for the shaping of the blocks since the residue did not absorb water from the cement-sawdust mixture.

According to results of the compressive strength tests, the reference mark was 1:8 (Table 7). It was actually the best performance for the production of blocks with a 5% replacement of sand by sawdust. Since this standard was not so high in cement, a greater economy was obtained in concrete block manufacture.

Table 7. Definition of standard with a 5% replacement.

Mixture	1:8
Unit mixture	1: 3.95:0.05 : 4
Water/cement	0.60
Residue Moisture	30%

The following procedure was used to obtain the reference mark: (a) initially a pre-mixture of aggregates was carried out; (b) binder and half the amount of water were added; (c) the residue and the other half of water were added after 30 seconds. Maximum mixing time was 3 minutes.

Using the semi-automatic vibrating press, the concrete blocks were cast according to the following procedure: pouring of concrete, compactness by vibration and mechanical compression during a maximum 2-minute period of vibration-compaction to avoid concrete de-molding and to prevent cracks in the walls. Blocks were placed in an open place in the shade for the first two hours of curing. The blocks were then placed in a covered storage area, protected from direct sunlight, covered with a moist blanket for 24 hours and water-sprayed every 2 hours. Figure 6 shows blocks with wood residue after molding.

After three days, the blocks were placed in the laboratory for coating and on the seventh day compressive strength tests were carried out. Ten blocks were cast and tested for compressive strength (Table 8); one block was preserved. According to NBR 7173 (ABNT, 1982b), the minimum number of blocks for sampling in a qualifying round comprises 10 blocks and at least half should undergo the strength test performed according to NBR 7184 (ABNT, 1992) exactly as that of the reference blocks. Water absorption tests were conducted for all blocks according to NBR 7713 (ABNT, 1982a) and must achieve a 15% limit for individual rates and 10% for averages.

Figure 6. Blocks with 5% sawdust.

Table 8. Number of blocks per reference mark for each test.

Tests	Blocks	Age
Compressive strength	3	7 days
	3	28 days
Water absorption	3	28 days
Total	9	

Results and discussion

Table 9 shows results of water absorption tests for reference blocks and for sawdust-added blocks after 28 days. The legal limit of 15% water absorption for the individual rates was maintained for all blocks. In the case of average rates, only the reference and the sulfate-treated blocks met the 10% legal limit.

Table 10 shows the results of blocks' compressive strength to alkaline solution-treated residues. Loss of compressive strength in blocks with cement-wood composites when compared to reference blocks may be due to several factors. One factor may be the water absorption by fibers and particles and their subsequent release into the mortar. Since in current analysis the residue was added to the still moist mixture, absorption was supposed to be low. However, when in contact with wood fibers or particles, extracts may have been released in the mixture and must have directly contributed towards delay in the curing and hardening of the matrix.

Table 9. Result of water absorption tests.

Nº	Reference		Alkaline solution		Sulfate solution	
	Individual (%)	Average (%)	Individual (%)	Average (%)	Individual (%)	Average (%)
1	9.2		13.4		11.4	
2	8.2	8.97	11.2	13.13	9.6	10.40
3	9.5		14.8		10.2	

Table 10. Compressive strength – Alkaline solution.

Blocks T5 (with 5% sawdust)			
Strength after 7 days (MPa)		Strength after 28 days (MPa)	
Block 1	0.30	Block 4	1.35
Block 2	0.30	Block 5	1.40
Block 3	0.35	Block 6	1.42
Average	0.32	Average	1.39

This fact may be perceived in strength gain during the first days, which was very low even with CP V ARI and the treatment employed. An increase, ranging between 3.5 and 4 times that of the initial seven days, was reported between the seventh and the twenty-eighth day. This fact indicated that hydration reaction was delayed due to the fiber-released extracts. Table 11 shows results of aluminum sulfate-treated fibers.

Table 11. Compressive strength – Sulfate solution.

Blocks T5 (with 5% sawdust)			
Strength after 7 days (MPa)		Strength after 28 days (MPa)	
Block 1	1.30	Block 4	3.35
Block 2	1.35	Block 5	4.30
Block 3	1.42	Block 6	4.30
Average	1.36	Average	3.98

A comparative analysis showed that block casts with aluminum sulfate-treated residues had a significant increase in compressive strength results in the case of 5% fine aggregate replacement when compared to the lime-based treatment. Figure 7 presents the results of the blocks' average compressive strength.

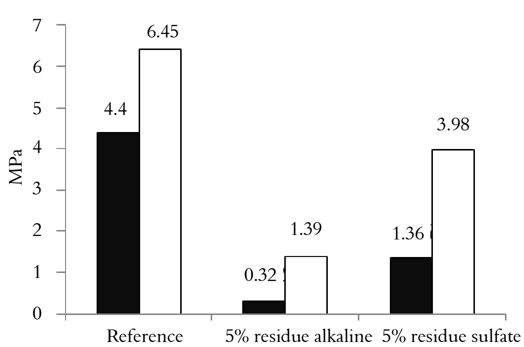

Figure 7. Compressive strength of reference blocks and of blocks with 5% wood residue.

The blocks with aluminum sulfate-treated residues had an average increase of 2.93 times in compressive strength when compared to average result of alkaline solution-treated samples, although lower than the reference standard. When the resistance of blocks with sawdust was analyzed, only blocks treated with 5% aluminum sulfate showed strength after 28 days and thus compatible with the regulatory specifications.

Conclusion

Concrete blocks with alkaline solution-treated wood residues failed in resistance and were incompatible with the regulatory specifications and blocks were not considered suitable for construction.

The blocks with sulfate solution-treated wood residues showed individual and average compressive strength rates above the regulatory requirements after 28 days of trial, favoring the blocks production.

When the rate of water absorption by the blocks with wood residues was considered, only aluminum sulfate-treated blocks met the limits prescribed by standard norms. The fact also indicated a higher efficiency of this treatment for this physical quality.

Alkaline solution-treated sawdust was not effective and the treatment was insufficient to adequately inhibit the adverse effects of wood extracts release in concrete curing.

When the immersion of residue in an aluminum sulfate solution was taken into account, results were more effective for the wood species used since there was a considerable increase in the blocks' compressive strength rates.

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Received on August 4, 2011.
Accepted on September 26, 2011.