

CONCRETE PRODUCTION AND DEMOLITION WASTE AND LIME PRODUCTION WASTE AS THE RAW COMPONENTS OF NEW CONSTRUCTION MATERIAL¹

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Abstract

It was developed and patented new construction materials from concrete production and demolition waste and lime production waste. The main objective of the research was to utilize these two types of industrial wastes in large possible scale as new concrete's raw materials. The lime production waste was characterized by a high excess of SiO₂, Al₂O₃, CaCO₃, etc. The water absorption value of the mixtures samples after 90 days of open air strengthening reach till 12,0%, the uni-axial compression resistance – till 33 (average 29) MPa. The results of DRX and MEV studies of the compositions allow the explaining of such growing up of the resistance by the complex of reasons. Among them are the transformation of the initial mixture's minerals (Lime and Portlandite) to calcium, magnesium and ferrous amorphous and crystalline carbonates (Calcite, Dolomite e Ancerite); by chemical interaction of concrete waste with lime component and growing up of new amorphous and crystalline Calcium Hydro-Silicate forms; Tobermorite, Afwillite and CSH. Economic efficiency calculation was beside of the research tasks, but it must be rather high because of zero prices of raw materials. But the main expecting advantage of the material utilization is the environment protection by the way of wastes utilization.

Key words: Concrete wastes; Lime producing waste; Physico -chemical interaction.

DESENVOLVIMENTO DE NOVO MATERIAL DE CONSTRUÇÃO A TRAVES DE RESÍDUOS DE PRODUÇÃO E DEMOLIÇÃO DE CONCRETO

Resumo

Foi desenvolvido um novo material de construção de resíduos de concreto e resíduos de produção de cal. O objetivo principal desta pesquisa é utilizar o máximo possível destes dois tipos de resíduos como matérias-primas para um novo concreto. O resíduo de produção de cal foi caracterizado por um excesso de SiO₂, Al₂O₃, CaCO₃, etc. O valor da resistência à compressão uni-axial, em cura a seco, dos corpos-de-prova depois de 90 dias chegou a 33 (média 29) MPa, a absorção de água foi de 12,0%. Os resultados de DRX e MEV das composições permitem explicar o crescimento da resistência por meio de razões complexas. Entre elas é a transformação dos minerais da mistura inicial (Cal e Portlandita) para cálcio, magnésio e carbonatos amorfo e cristalinos férreos (Calcita, Dolomita e Ancerita); pela interação química dos resíduos de concreto com os componentes da cal e crescimento de cálcio amorfo e cristalino formando um novo Hidro-Silicato, como a Tobermorita, Afwillita e o grupo mineral CSH. O cálculo da eficiência econômica não foi objeto desta pesquisa, mas deve ser bastante alto por causa do custo zero das matérias-primas. A principal vantagem para a utilização deste material de construção a base de resíduos de concreto e resíduos de produção de cal é a proteção do meio ambiente.

Palavra-chave: Resíduos de construção e demolição; Resíduos de produção de cal; Interação físico-química.

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1 INTRODUCTION

The first facts of construction and demolition wastes (CDW) utilization as raw materials are cited from the ancient Rome epoch.⁽¹⁾ Researches in this field were began from 1928, but really massive usage of this type of materials began in Europe for the reconstruction of destroyed cities only after the finishing of Second World.⁽²⁾

Now in Europe annually are dumping near the 200 millions tons of concretes and rocks wastes. Such quantity is sufficient for the construction of six-row road between London and Rome.⁽³⁾

A quantity of CDW produced in many countries varying from 136 till 3359 kg-inhabitant/year^(4,5) and can be expected as 13% a 80% of all mass of municipal solid wastes.⁽⁶⁾

Offerman⁽⁷⁾ analyzed substitution of natural aggregates by CDW for concrete production. For the decreasing of water adsorption by small particles of CDW he replaced less then 4 mm granulometric fraction by natural sand.

Hansen⁽⁸⁾ demonstrated possibility of new concrete production from waste concrete with addition of fly ash without utilization of new cement in proportion of 79% concrete waste, 11% of fly ash and 10% of water.

New composites development from CDW with other industrial wastes can give advantages so economical as environment protection. But all the foregoing research works are devoted to the utilization of concrete of construction or demolition wastes with Portland cement. It were not founded some publications dedicated to using as a binder component of lime or, moreover, to lime production wastes. In accordance to research strategy of Environment Technology Laboratory (LTA) of Paraná Federal University (UFPR) it were developed the material from only 100% of industrial wastes as raw materials, namely concrete of construction and demolition wastes and lime producing waste.

2 OBJECTIVES OF THE RESEARCH

1. To develop composites for producing of new material from concrete construction and demolition waste and lime production waste;
2. To study physico-chemical properties of the best composites and their accordance with Brazilian construction standards;
3. To decrease a cost price of construction materials (blocks and bricks) without loosing of their mechanical properties.

3 METODOLOGY

3.1 Samples Preparing

For realization of this idea it was collected some representative samples of construction and demolition wastes and lime producing waste. They were dried, milled and sieved through 1.18 mm sieve. After homogenization of the both wastes with different percentage compositions (Table 1) they were hydrated in lime/water relationship 1/1. Hydrated samples were kept before the compacting during 40 minutes, loading force was 10 MPa. Compacted samples were stored on the open air.

Table 1. Compositions of the mixtures under study

№	Samples composition , weight %		
	Concrete waste	Lime production waste	Water
1	90	10	10
2	85	15	15
3	80	20	20
4	75	25	25
5	70	30	30
6	65	35	35
7	60	40	40

Water absorption capacity tests (W_{abs}) in accordance with Brazilian standard (9) were calculated with formula:

$$W_{abs} = (M_{humid} - M_{dry}) / M_{dry} \times 100\%,$$

where:

M_{humid} – mass of the sample after 72 hrs of water saturated samples and 5 hrs in water bath,

M_{dry} - mass of the sample after 72 hrs of drying with temperature 105⁰C

3.2 Research Methods

The research was conducted by the complex of the following methods: XRD, XRF, SEM, AAA, uni-axial compression resistance and water absorption.

Table 2 – Chemical composition of the raw materials under study (by XRF method)

Elements	Compositions and analysis error, weight %			
	Concrete waste		Lime production waste	
	Compos.	A.D.	Compos.	A.D.
SiO ₂	55.82	0.1	2.82	0.02
CaO	21.7	0.06	47.69	0.07
Al ₂ O ₃	8.47	0.03	0.25	0.008
Fe ₂ O ₃	3.69	0.03	0.24	0.008
MgO	3.13	0.02	33.10	0.06
K ₂ O	2.51	0.01	0.05	0.002
SO ₃	2.31	0.02	0.03	0.002
Na ₂ O	0.74	0.01	-	-
TiO ₂	0.67	0.01	0.04	0.003
P ₂ O ₅	0.16	0.005	0.02	0.001
MnO	0.09	0.004	-	-
C	-	-	15.74	-
Total	100	-	100	-

The main components of concrete wastes together with average deviation are presented in Table 2. The lime production waste mainly contains CaO and MgO with total contain only 80.8% with high (15.74%) value of underfired limestone. In accordance with Brazilians standards^[10] this total value must be no less than 88 or

90%. That is why this product can not be sold as construction material and must be classified as industrial waste. Usually it is used for acid soils neutralization or rejected to industrial waste dump.

4 RESULTS AND DISCUSSIONS

4.1 Compression Resistance

Resistance to uni-axial compression was measured to 6 samples of each material. The average of obtained results is putted in Table 3 together with average deviation. The hardening process of all compositions is increasing constantly almost without some visible digressions till almost 29 MPa to 90-days samples' age.

Table 3. Resistance compression results

№	Statistical parameters	Samples resistance after hardening (days)					
		3	7	14	28	60	90
1	Average	7.27	8.89	8.88	10.13	12.33	13.84
	Deviation	0.58	0.92	1.33	1.33	1.03	0.71
2	Average	9.04	9.11	9.61	1.96	13.01	16.31
	Deviation	1.34	1.86	1.51	2.37	1.61	1.42
3	Average	8.53	9.94	11.06	11.66	15.71	18.58
	Deviation	1.43	1.72	0.80	1.27	1.00	2.65
4	Average	12.71	14.88	14.76	15.48	21.42	22.14
	Deviation	2.68	1.00	1.16	2.17	1.90	2.00
5	Average	15.91	18.29	19.72	18.35	24.12	26.03
	Deviation	1.57	1.32	2.75	2.46	1.32	3.41
6	Average	16.49	18.10	19.69	21.10	26.07	27.46
	Deviation	2.08	1.23	2.31	1.78	2.60	1.83
7	Average	15.12	16.47	20.51	19.50	25.18	28.97
	Deviation	4.48	3.99	1.96	3.01	4.37	3.25

The resistance increase with increasing of lime content. Therefore the best result demonstrates composition 7 with 40% of lime content. But the strength difference between material 7 (28.97 MPa) and materials 6 and 5 (27.46 and 26.03 MPa with 35 and 30% of lime content correspondingly) is not very big. From economic point of view may be it will be possible to choose these two last compositions for industrial application.

Table 4– Water absorption of CDW and lime production waste composites.

№	Statistical parameters	Weight after 28 days (g)		Calculation, (%)	
		After 72 hrs of drying	After water bath	Abs _{cp} dry	Abs _{cp} humid
1	Average	13.30	14.96	12.47	12.47
	Deviation	0.03	0.01		
2	Average	13.30	14.86	11.75	11.76
	Deviation	0.028	0.04		
3	Average	13.28	14.82	11.59	11.56
	Deviation	0.020	0.02		
4	Average	13.29	14.82	11.57	11.50
	Deviation	0.05	0.068		
5	Average	13.30	14.89	12.09	12.00
	Deviation	0.05	0.046		
6	Average	13.12	14.82	13.09	12.99
	Deviation	0.19	0.24		
7	Average	13.51	14.92	10.52	10.38
	Deviation	0.33	0.26		

Data of Table 3 show that water absorption value of all composites under study is fluctuated in the limits from 10.38 till 13.09%. The best meanings (10.38 and 10.52%) have material 7 with 40% of lime waste containment.

4.2 Physico-chemical Processes of the Material Strengthening

Studying of mineralogical composition of dry initial mixtures of the wastes by XRD method enable to state the presence of the following groups of minerals:

- 1. natural components of concrete waste aggregates - Quartz (SiO_2), Microcline (KAlSi_3O_8), Orthoclase (KSi_3AlO_8), Calcium Carbonate (CaCO_3) and Calcium Silicate (Ca_2SiO_4);

Table 5. Change of mineral compositions of the materials under study during their hardening

XRD-peaks positions description during hydration after (days)								Matched by minerals
Initial, dry		3		28		90		
d, Å	Int, %	d, Å	Int, %	d, Å	Int, %	d, Å	Int., %	
3.856	0.52	3.86	1.22	3.85	1.36	3.85	1.59	Calcite
3.186	1.72	3.19	5.66	3.19	1.57	3.19	1.79	Afw., Tb
3.104	0.70							Prtld.
3.031	4.87	3.03	12.6	3.03	13.2	3.03	13.9	Calcite; Mclr; C-S-H; Tb
2.896	0.81	2.90	1.14	2.90	1.20	2.90	1.28	C-S; Anc.
2.777	1.93							Cal
2.628	3.74	2.63	1.94	2.62	2.31	2.63	5.14	Prtld; Tb; CSH
2.494	0.44	2.50	0.96	2.49	1.17	2.49	1.42	Calcite
2.404	5.22	2.40	3.80	2.40	4.13	2.40	5.25	Cal; Dolomite; Ort.
2.280	6.62	2.28	6.85	2.28	6.12	2.28	12.4	Q; C-S; CSH; Calcite; Afw
2.106	12.6	2.11	10.2	2.10	8.85	2.11	11.5	Periclase; Calcite; Tb
1.923	1.36	1.92	1.60	1.92	1.98	1.93	2.41	Calcite; Prtld; C-S; Tb; Afw
1.875	0.50	1.88	1.33	1.87	1.87	1.88	1.95	Calcite; C-S
1.817	8.74	1.82	11.7	1.82	5.96	1.82	24.8	Q; Tb; Dlm; Ancerite; CSH
1.798	1.35	1.80	1.21	1.79	1.23	1.80	1.81	Q; Afw; Prtl; Dolomite
1.673	1.90	1.67	3.18	1.67	2.26	1.67	3.41	Q; Ortoclase
1.604	0.10	1.60	0.50	1.60	0.55	1.61	0.67	Q; Calcite; CSH; Afw; Tb
1.452	1.80	1.45	0.83	1.45	0.78	1.45	1.31	Q; Ort; Prtl; Ancerite

Legend:

Q = Quartz (SiO ₂)	Prtld = Portlandite Ca(OH) ₂	Periclase = MgO	Dolomite = Ca Mg (CO ₃) ₂
Ort = Ortoclase KSi ₃ AlO ₈	C-S = Calcium Silicate Ca ₂ SiO ₄	Calcite = CaCO ₃	Anc = Ancerite Ca(Mg.Fe)(CO ₃) ₂
Mcr = Microcline KAlSi ₃ O ₈	C-S-H = Calcium Silicate Hidrate Ca ₂ SiO ₄ H ₂ O	Tb = Tobermorite Ca ₅ Si ₆ O ₁₆ (OH) ₂	Afw = Afwillite Ca ₃ (SiO ₃ OH) ₂ 2H ₂ O

2. products of hydration - Afwillite Ca₃(SiO₃OH)₂2H₂O, C-S-H - Calcium Silicate Ca₄Si₅O_{13.5}(OH)₂ and Calcium Silicate Hidrates (Ca_{1.5} SiO_{3.5}.xH₂O);

3. binding materials, such as and Lime (CaO). Periclase (MgO). Calcium Hydroxide - Portlandite Ca(OH)₂;

4. carbonates - Calcite Ca(CO₃)₃.

On the Table 5 are given in comparison the changes of some peaks (as positions so intensities) during the initial dry mixture hydration (3, 28 and 90 days). Comparisons of X-ray diffractograms of dry initial mixtures and of samples hydrated during 3 days demonstrate disappearance of Lime (d=2.777 Å) and Portlandite (3.104 Å) peaks and appearance of material hydration products, such as Tobermorite (Ca₅Si₆O₁₆(OH)₂) with d=3.186, 2.628, 1.817, 1.798 and 1.604 Å, Ancerite – Ca(Mg.Fe)(CO₃)₂ with d = 2.897, 1.8182 e 1.452 Å and appearance of many additional peaks of Calcite Ca(CO₃)₃ with d=3.852, 3.032, 2.494, 2.280, 2.104, 1.916, 1.8741 e 1.604Å.

On the 28-th day diffractogram, Dolomite CaMg(CO₃)₂ with d = 2.403, 1.818 e 1.793 Å. On the 90-days diffractogram repeat all minerals earlier appointed.

That means, that during the process of the mixture hydration it was fixed the events of synthesis and improvement of crystal lattices of calcium carbonates Calcite, Dolomite and Ancerite.

Only two of all peaks of this carbonates are free of the coincidence with other minerals peaks, namely peaks of Calcite with $d = 3.8560$ e 2.4949 \AA . But these peaks intensities on RX diffractograms are increasing only on 0.98 and 1.08% correspondingly. Practically the same growth of crystals peaks intensity is visible for other above mentioned minerals.

On the of SEM micrographs (Figures 3 and 4) there are visible amorphous-like new formations. Similar forms were observed^(11,12) on the surfaces of the mixtures of clayey soils with ferrous slag during the studying of their chemical interaction and structure formation. Obtained resistance strength of the samples reached 50 MPa without appearance of some crystal structures on X-rays diffractograms. After using of numeral research methods authors^(11,12) came to conclusion, that the only explanation of such resistance was the sol-gel strengthening of amorphous new formations. It seems, the materials under study also have rather big quantity of amorphous new formations, binging aggregates of concrete waste.

Menta and Monteiro⁽¹³⁾ came to similar conclusion after C-S-H new colloid formation of Portland cement studying. The most conclusive in such cases also was SEM method.

It is well seen on the SEM micrographs the structure of concrete waste (Figure 3-a and b) with inclusions of stone and sand aggregates. Their surfaces are covered by amorphous-like formations and do not contains some crystal bodies.

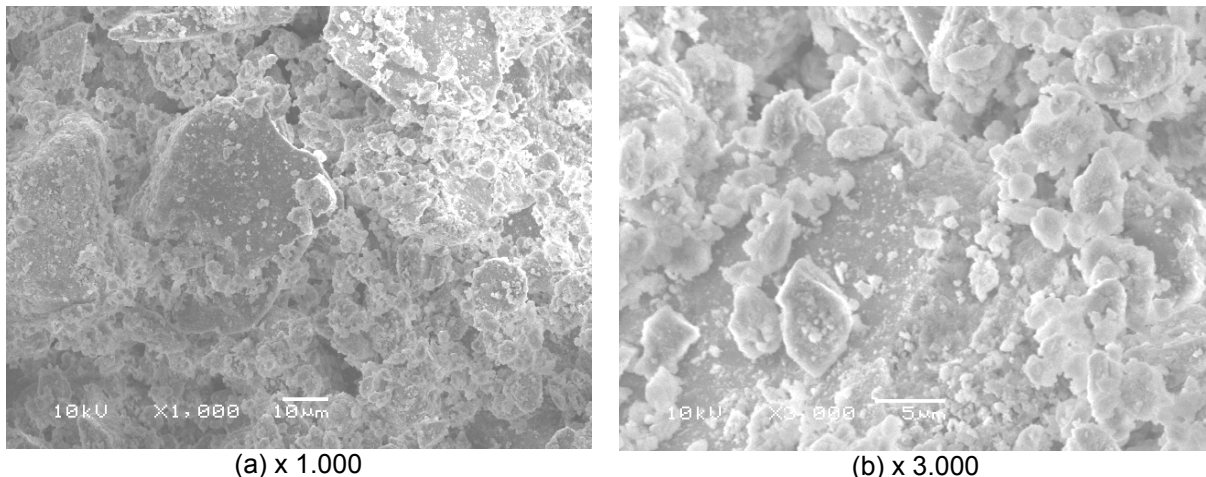


Figure 3 – Micrographs of initial concrete waste.

This type of structure remains overwhelming (Figure 4-a) in the process of the mixture hydration and interaction. But in some surface points crystal druse (nodule) appeared (Figure 4-b). This fact confirms the XRD data about partly crystal nature of new formations, which are strengthening the material's volume.

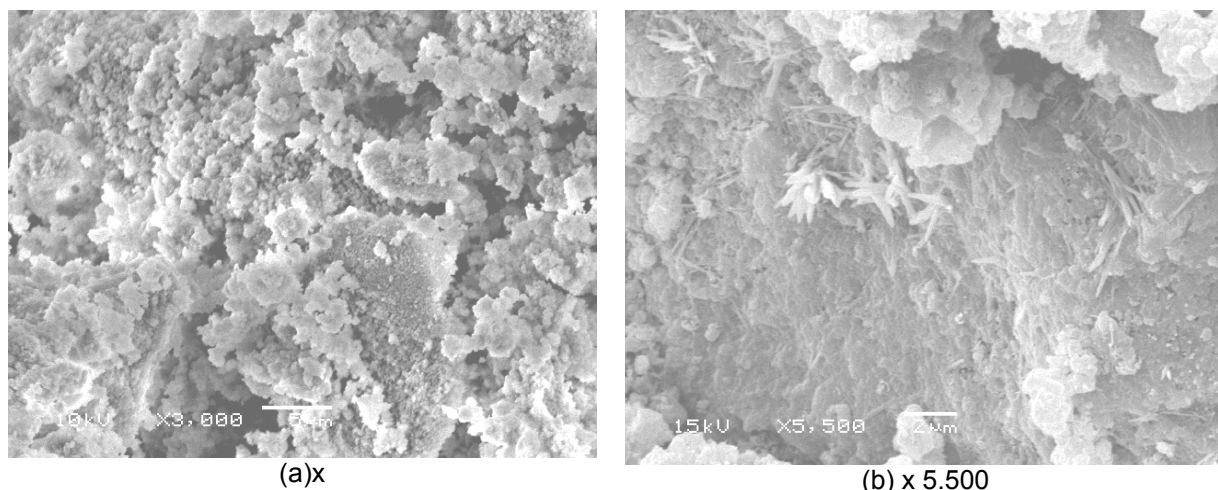


Figure 4 – Micrographs of the material from concrete waste and lime production waste after 90 days of hydration.

5 CONCLUSIONS

1. Realization of this research confirms experimentally an idea of possibility of new construction material obtaining by utilization as raw material a concrete producing and demolition wastes in different mixtures with lime production waste.

2. All compositions under study demonstrated rather high value of mechanical properties (uni-axial compression resistance and water adsorption), comparable with of Brazilian demands. The best mechanical properties were obtained for the composition with 40% of lime waste and 60% concrete waste with average resistance 26 MPa on the 90-th day of hydration. But sufficient value of mechanical properties of the compositions 5 and 6 with 30 and 35% containment of lime production wastes make them rather competitive with composition 7. Others compositions also can be used for different construction goals.

3. It was established by XRD and SEM methods that during initial mixtures hydration and hardening the following processes occurred:

- complete transformation of lime (CaO) and partially of Portlandite $\text{Ca}(\text{OH})_2$ to the different carbonates forms, such as Calcite CaCO_3 , Dolomite $\text{CaMg}(\text{CO}_3)_2$ e Ancerite $\text{Ca}(\text{Mg.Fe})(\text{CO}_3)_2$.

- synthesis and improvement of crystalline structures - Tobermorite $\text{Ca}_5\text{Si}_6\text{O}_{16}(\text{OH})_2$, afwillite $\text{Ca}_3(\text{SiO}_3\text{OH})_2 \cdot 2\text{H}_2\text{O}$, of Calcium Hydro-Silicates (CSH) $\text{CaO SiO}_2 \cdot \text{H}_2\text{O}$;

- growing up of significant quantity of amorphous-like new formations, which are more visible with SEM method, especially on the big magnifications;

A synthesis of these three groups of new formations can explain the strength increasing of the composites of concrete wastes and lime production resistance

4. A calculation of the economical efficiency was not among the research objectives. Nevertheless the utilization of industrial wastes as free of charge raw materials undoubtedly will economize perceptibly the price of civil construction.

5. Utilization of this widely spread industrial wastes in the civil construction practice can give a real possibility of significant decrease the environment pollution.

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REFERENCES

- 1 Petrucci E. G. R. *Materiais de Construção*. 2ª edição. Editora Globo, 1976.
- 2 Levy. S.M. e Helene. P.R.L. *Reciclagem de Entulhos na Construção Civil a Solução Política e Ecologicamente Correta*. In: Simpósio Brasileiro de tecnologia de argamassas, 1º Goiânia, pp. 315-325, Brasil, 1995.
- 3 Laguette M. J. *Reciclaje: la clave para la conservación de recursos*. Construction Pan-Americana, julho 1995.
- 4 John V. M. *Reciclagem de resíduos na construção civil – contribuição à metodologia de pesquisa e desenvolvimento*. Universidade de São Paulo, 102p., 2000
- 5 Pinto T.P. *Metodologia para a gestão diferenciada de resíduos sólidos da construção urbana*. Universidade de São Paulo, 189p., 1999.
- 6 Ângulo S.C. *Variabilidade de agregados graúdos reciclados de resíduos de construção e demolição reciclados*. Dissertação (Mestrado), 155p., Escola Politécnica, Universidade de São Paulo, 2000.
- 7 Offermann, E. H. *O futuro da reciclagem de entulho de construção (tradução)*. Hochschuljournal Essen, n. 52, 1987.
- 8 Hansen T. C. *Recycled concrete aggregate and fly ash produce concrete without strength cement*. Cement and Concrete Research. v. 20. n.3. p. 355-356, 1990.
- 9 Associação Brasileira de normas técnicas, NBR 9778. *Argamassa e concreto endurecidos – Determinação da absorção de água por imersão – índice de vazios e massa específica*.
- 10 Associação Brasileira de Normas Técnicas, NBR 6453. *Cal virgem para construção civil – Requisitos*.
- 11 Mymrin V.A., Ponte H.A., Ponte M.J.J.J. *Structure formation of slag-soil construction materials*, Materials and Structures, v. 38, 275, pp.107-113, 2005.
- 12 Mymrin V.A., Ponte H.A. *Oil shale ash utilization as independent binder of natural clayey soils for road and airfield base construction*. Particulate Science and Technology, v. 23, 1, 99-107, 2005.
- 13 Menta, P. K.; Monteiro, P.J.M. *Estrutura, Propriedades e Materiais*. PINI. São Paulo, 1994.