NEW CONSTRUCTION MATERIAL FROM CONCRETE PRODUCTION AND DEMOLITION WASTE AND LIME PRODUCTION WASTE

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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 SiO_2, Al_2O_3, $CaCO_3$, 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: Construction and demolition wastes, lime producing waste, physico-chemical interaction, strengthening, new structure formation.

1. INTRODUCTION

The first facts of construction and demolition wastes (CDW) utilization as raw materials are cited from the ancient Rome epoch (Angulo, 2000). Researches in this field were begun 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 (Laguette, 1995).

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-raw road between London and Rome, (Laguette, 1995).

A quantity of CDW produced in many countries varying from 136 till 3359 kg-inhabitant/year (John, 2000; Pinto, 1999) and can be expected as 13 a 80% of all mass of municipal solid wastes, (Angulo, 2000).

Offerman (1987) 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 (1990) 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 physic-chemical properties of the best composites and their accordance with Brazilian construction standards.

3. METHODOLOGY

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. Compacting process had two stages: preloading till 15 MPa, unloading and second loading till 30 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 in accordance with Brazilian standard (Pinto, 1999) were calculated with formula:

$$W\ abs. = (M_{humid} - M_{dry}) / M_{dry} \times 100\%, \quad (1)$$

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 105 ºC;
Abs_{cp} dry
Abs_{cp} humid

3.2. Research methods

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.E.	Compos.	A.E.
SiO_2	55.82	0.1	2.82	0.02
CaO	21.7	0.06	47.69	0.07
Al_2O_3	8.47	0.03	0.25	0.008
Fe_2O_3	3.69	0.03	0.24	0.008
MgO	3.13	0.02	33.10	0.06
K_2O	2.51	0.01	0.05	0.002
SO_3	2.31	0.02	0.03	0.002
Na_2O	0.74	0.01	-	-
TiO_2	0.67	0.01	0.04	0.003
P_2O_5	0.16	0.005	0.02	0.001
MnO	0.09	0.004	-	-
C	-	-	15.74	
Total	100	-	100	-

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

The main components of concrete wastes are SiO_2, CaO, and Al_2O_3 (Table 2). The lime production waste mainly contains CaO and MgO with total contain only 80.79% with high (15.74%) value of underfired limestone. In accordance with Brazilians standards (Angulo, 2000) 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 DISCUSSION

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.

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.

Table 3– 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		

4.2. Physic-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:

- 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);
- products of hydration - Afwillite $Ca_3(SiO_3OH)_2 2H_2O$, C-S-H - Calcium Silicate $Ca_4Si_5O_{13.5}(OH)_2$ and Calcium Silicate Hidrates ($Ca_{1.5}$ $SiO_{3.5}.xH_2O$);
- binding materials, such as and Lime (CaO). Periclase (MgO). Calcium Hydroxide - Portlandite $Ca(OH)_2$;
- carbonates - Calcite $Ca(CO)_3$.

On the Table 4 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 difractograms 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 ($Ca_5Si_6O_{16}(OH)_2$) with d=3.186, 2.628, 1.817, 1.798 and 1.604 Å, Ancerite – $Ca(Mg.Fe)(CO_3)_2$ with d = 2.897, 1.8182 e 1.452 Å and appearance of many additional peaks of Calcite $Ca(CO)_3$ with d=3.852, 3.032, 2.494, 2.280, 2.104, 1.916, 1.8741 e 1.604Å.

On the 28-th day diffractograme, Dolomite $CaMg(CO_3)_2$ 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 Å. 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 (Fig. 3 and 4) there are visible amorphous-like new formations. Similar forms MYMRIN (1980, 1981, 2003) observed 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 Mymrin 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.

Table 4. Change of mineral compositions of the materials under study during their hardening

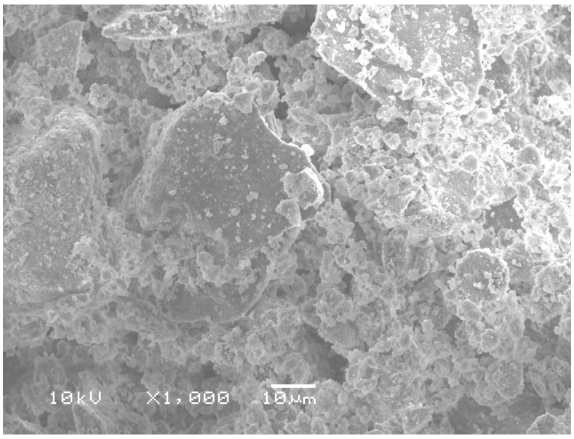
XRD-peaks positions description during hydration after (days)								Matched by minerals
Initial, dry		3		28		90		
d, Å	Int, %	d, Å	Int, %	d, Å	Int, %	d, Å	Int.. %	
3.856	0.52	3.86	1.22	3.85	1.36	3.85	1.59	Calcite
3.186	1.72	3.19	5.66	3.19	1.57	3.19	1.79	Afw., Tb
3.104	0.70							Prtld.
3.031	4.87	3.035	12.69	3.03	13.2	3.03	13.9	Calcite; Mcrl; 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	Calcita
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; Prtld; Ancerite

Legend:

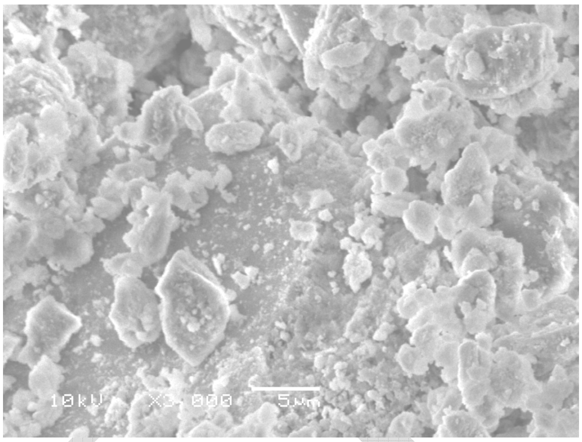
Q = Quartz (SiO2)	Prtld = Portlandite $Ca(OH)_2$	Periclase = MgO	Dolomite = Ca Mg $(CO_3)_2$
Ort = Ortoclase KSi_3AlO_8	C-S = Calcium Silicate Ca_2SiO_4	Calcite = $CaCO_3$	Anc = Ancerite $Ca(Mg.Fe)(CO_3)_2$
Mcr = Microcline $KAlSi_3O_8$	C-S-H = Calcium Silicate Hidrate Ca_2 SiO_4 H_2O	Tb = Tobermorite Ca_5 Si_6 O_{16} $(OH)_2$	Afw = Afwillite $Ca_3(SiO_3OH)_2$ $2H_2O$

Mehta and Monteiro (1994) 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 (Fig. 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.



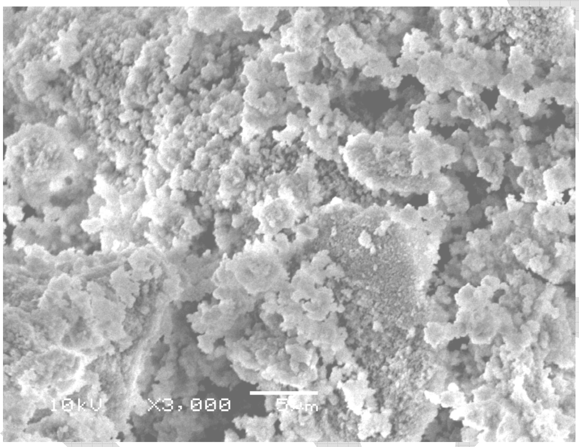
(a) x 1.000



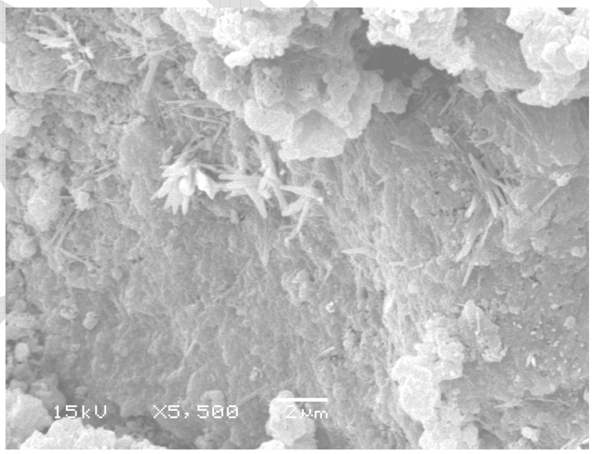
(b) x 3.000

Figure 3 – Micrographs of initial concrete waste

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



(a)x



(b) x 5.500

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 $Ca(OH)_2$ to the different carbonates forms, such as Calcite $CaCO_3$. Dolomite $CaMg(CO_3)_2$ e Ancerite $Ca(Mg.Fe)(CO_3)_2$.
- synthesis and improvement of crystalline structures - Tobermorite $Ca_5Si_6O_{16}(OH)_2$, afwillite $Ca_3(SiO_3OH)_2$ $2H_2O$, of Calcium Hydro-Silicates (CSH) CaO SiO_2 H_2O;
- 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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