Chapter 114

Concrete waste as a substitute for cement: Evaluation of compression strength and CO_2 emissions

https://doi.org/10.56238/methofocusinterv1-114

Dayana Ruth Bola Oliveira
Postgraduate Program in Civil Engineering | Federal University of Paraná
E-mail do autor correspondente: dayruth@gmail.com

Gabriela Leite
Laboratory of Performance, Structural and Materials (LADEMA) | Federal University of Latin American Integration (Unila)

Melissa Pastorini Proença
Laboratory of Performance, Structural and Materials (LADEMA) | Federal University of Latin American Integration (Unila)

Kathleen Dall Bello de Souza Risson
Laboratory of Performance, Structural and Materials (LADEMA) | Federal University of Latin American Integration (Unila)

Edna Possan
Laboratory of Performance, Structural and Materials (LADEMA) | Federal University of Latin American Integration (Unila)

José Marques Filho
Postgraduate Program in Civil Engineering | Federal University of Paraná

ABSTRACT
Compressive strength and CO_2 emissions of Portland cement (CP) matrices were evaluated, with the replacement of 0%, 7%, 15%, and 25% of concrete waste as a function of waste processing time (0, 0.5, 2, and 6 h). The results indicate that the compressive strength in the matrix, with 15% and 25% of treated waste, meets the requirements for class C40, and C32 of the Brazilian technical standard for PC, with the potential to mitigate emissions per ton of cement by up to 25%. With concrete waste, it was possible to reduce 13% of cement consumption/MPa a

Keywords: Concrete waste. Particle treatment. CO2 emissions.

1 INTRODUCTION

Considering that CO2 emissions from the cement industry correspond to approximately 5 to 7% of anthropogenic emissions (BORDY et al., 2017; SCRIVENER et al., 2018), mainly from the decarbonization of carbonate rocks in the clinkerization process, and that this step is responsible for 70% of total emissions from cement manufacturing (SNIC, 2019), global actions such as the Paris Agreement (2015) and Agenda 2030 (2016-2030), aimed at reducing anthropodynamic environmental impacts, mainly associated with the production of Portland cement clinker are of great importance. It makes up the prospect that growth in demand for Portland cement by 2050 will reach the level of 6 billion tons (SCRIVENER et al., 2018), resulting from the need to build and maintain the built environment, the high housing deficit and infrastructure and expected population growth.

In this context, waste concrete (RC) replacing Portland cement can be an alternative to reduce emissions associated with cement and the problem of waste disposal. In addition to being a strategy producing matrices with low clinker consumption (kg/m³/MPa) and resistance that meets regulatory parameters. Therefore, this study presents the compressive strength and emissions of Portland cement, produced with different contents and processing times of the concrete waste to be used as a substitute for cement.

2 EXPERIMENTAL PROCEDURE

To determine the influence of the concrete waste, when used in place of Portland cement, the compressive strength of the cement was evaluated using the procedures of NBR 7215 (2019), according to the proportions presented in Table 1 and procedures in Figure 1. For the fixed mix 1:3:0.48, substitutions were made in the volume of Portland cement by treated waste of 0, 7, 15, and 25%. Compressive strength was determined at 28 and 91 days, taking the average of 4 cylindrical samples (50mm x 100mm) for each age, cured in water saturated with lime.

Figure 1 - Molding and submerged curing of specimens in mortar

Source: The authors (2023) CP V ARI cement with a specific mass of 3.09 g/cm³ and Blaine fineness of 4,459 cm²/g was used. As a fine aggregate, normal sand with granulometric distribution #16 (1.18mm), #30 (0.60mm), #50 (0.30mm) #100 (0.150mm) was used according to NBR 7215 (2019).

Source: The authors (2023)

The evaluated residue was obtained by processing specimens of discarded concrete subjected to different types of physical and mechanical treatment (due to confidentiality issues, the treatment process is not presented in this article).

Table 1 - Consumption of materials of produce 1m³ of mortar (NBR 7215, 2019), emissions of cement and composites with concrete residue, and binder index (kg of cement to produce 1 MPa)

Residue		Material Consumption (kg/m³)*		Emissions CO_2	Performance	
Content (%)	Treatment (h)	Portland Cement (C)	The residue (RCF)	Cimento de RCF (kg.CO_2/m³)	Fc (91 days)**	Binder index (Kg.C/MPa)
0	Ref	510,84	0	866,0	50,40	10,16
7	0h	473,89	29,27	805,7	31,04	15,35
	0,5h	473,99	29,72	806,4	41,66	11,43
	2h	474,23	30,86	808,6	42,35	11,25
	6h	474,27	31,09	814,6	48,88	9,75
15	0h	431,88	62,72	736,7	33,40	13,04
	0,5h	432,08	63,69	738,3	43,62	9,98
	2h	432,54	66,13	743,1	46,93	9,28
	6h	432,63	66,62	755,9	38,50	11,31
25	0h	379,71	104,53	650,5	32,03	11,99
	0,5h	380	106,15	653,1	30,70	12,51
	2h	380,68	110,22	661,2	33,80	11,37
	6h	380,81	111,04	682,6	29,90	12,85

* For all mixtures, 1532.53 kg of fine aggregate (IPT standardized sand) was used.
** Compressive strength and binder index data referring to the age of 28 days are shown in figures 4 and 5.

Source: The authors (2023)

The specific mass of the materials was determined according to NBR 16605 (2017) by the Le Chatelier method. Blaine fineness was performed using Polyperm 200 equipment – ACP Instruments. Laser granulometry was carried out in a granulometer (Cilas 1190). The BET test on Quantachrome Nova 3200e equipment. Scanning electron microscopy (SEM) was performed using Zeiss equipment – EVO MA10. The pozzolanic activity was performed based on NBR 5752(1). X-ray diffraction (XRD) in Panalytical diffractometer and Crystallography Open Database. Chemical analysis by x-ray fluorescence (FRX) in Panalytical Axios Max spectrometer.

For the analysis of emissions, the average of the maximum and minimum limits of NBR 16697 (2018) and 3.5% of calcium sulfate content present in the cement composition were considered. For the analysis of emissions (equation 1 and equation 2), it was adopted that the production of each ton of clinker emits 834kg.CO2/t (WBCSD, 2019), limestone filler emits 11kg.CO2/t (CIS/ECRA, 2009) and calcium sulfate emissions were neglected. For the processing of recycled aggregate, 6.36 Kg.CO2/t (PAZ, 2023) was considered. To estimate the emissions from the RCF treatment, emissions of 49 kg.CO2/t (CZIGLER, 2020) from clinker production was considered, divided by the 2-hour processing time, to obtain unit values of emissions equivalent to the RCF treatments Transport emissions were not considered.

The binder index (kg.C/MPa) indicates how many kg of cement were used to obtain 1 MPa, corresponding to the relationship between the consumption of Portland cement used in the mixture and the compressive strength obtained at the age of 91 days.

3 RESULTS DISCUSSION

3.1 CHARACTERIZATION OF MATERIALS

The waste obtained as an initial parameter (0h) showed a pozzolanic activity index of 66.18%, below the minimum limit recommended by NBR 5752 (2014) of 90%. Figure 2 shows the relationship between the average diameter and the Blaine fineness of the concrete waste as a function of the treatment employed. It is observed that in the first hours of processing, there is a considerable increase in the surface area of the particles. After 6 hours of comminution, low efficiency is observed in the process considering the energy and time required to increase the surface area; the residues shown in figure 3 were used in this study.

Figure 3: Concrete waste powder evaluated

Source: The authors (2023)

It can be seen in Table 2 that the longer the grinding time, the greater the specific mass of the residues, and the smaller the average diameters obtained by the laser granulometry test. Concerning the residue 0h, the d50 is inferior in 56% 0.5h, 75% 2h, and 83% 6h, respectively.

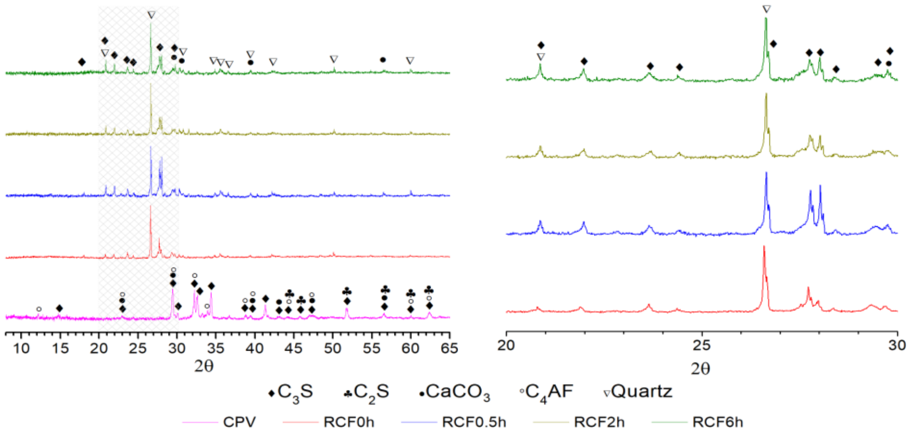
Table 2 - Results of the physical characterization of the materials

Material	CP V- ARI	0h	0.5 h	2 h	6 h
ρ (g/cm^3)	3,14	2,57	2,61	2,71	2,73
Blaine (cm^2/g)	4215,7	1732,3	4350,7	6583	7160
Average diameter (µm)	14,53	54,85	24,31	13,51	9,27
BET (cm^2/g)	65.750	96.690	99.510	74.370	51.370

Source: The authors (2023)

In the diffractograms (Figure 4), it is possible to observe that the main common phases found in the materials correspond to Alite and Calcite. In the residue, there is a predominance of quartz, which comes from the fine natural aggregate used in the production of the concrete that gave rise to the residue, corroborating the FRX analyses (Table 3) that indicated high levels of silica (SiO_2 > 40%), and low levels of CaO (three times less than cement).

Figure 4 - XRD analysis of materials



Source: The authors (2023)

Table 3 - X-ray fluorescence of materials

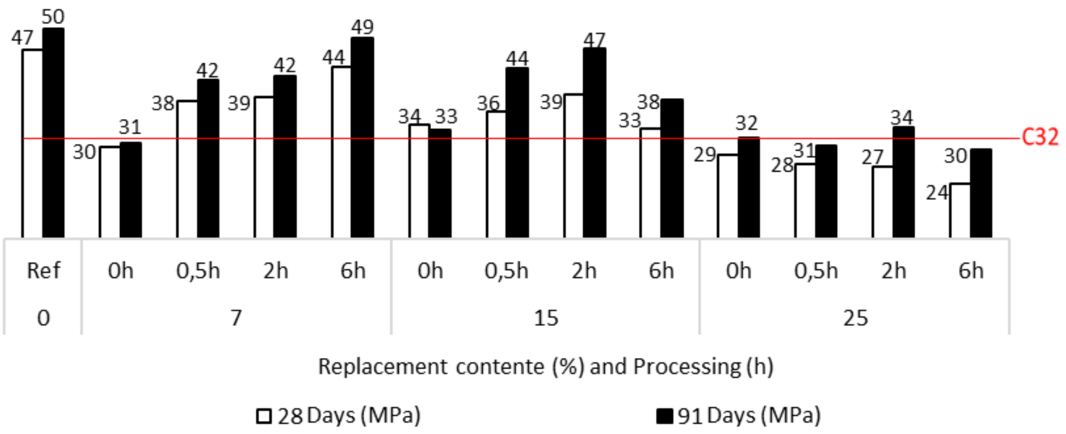
Material	SiO_2	CaO	Fe_2O_3	Al_2O_3	MgO	Na_2O	TiO_2	K_2O	SO_3	loss to fire
CPV	19,7	60,9	3,1	4,6	2,5	0,2	0,2	0,8	3,9	3,6
RC 0.5h	43,1	18,5	11,8	10	2,5	1,3	1,8	1,1	0,8	8,3
RC 2h	43,1	18,5	11,6	9,7	2,7	1,2	1,7	1,1	0,9	8,8
RC 6h	44,2	17,5	11,7	9,6	2,7	1,3	1,7	1,1	0,8	8,73

Source: The authors (2023)

3.2 MECHANICAL PERFORMANCE OF MORTARS

Note the gradual increase in compressive strength as the hydration ages advance (Figure 5). It was found that adding 7% and 15% of residue, regardless of the treatment process, led to mechanical strengths that meet the normative parameter of class 32 MPa Portland cement after 28 days. All matrices with contents of 7% residue and 15% RC 2h reached the C40 level at 28 days, and at 91 days, the matrices containing 15% RC 0.5h. It is noted that in the long term, mortars with residue tend to show resistance increases, compensating for the dissolution process commented by John et al. (2018).

Figure 5 - Effect of treatment time and replacement levels on compressive strength

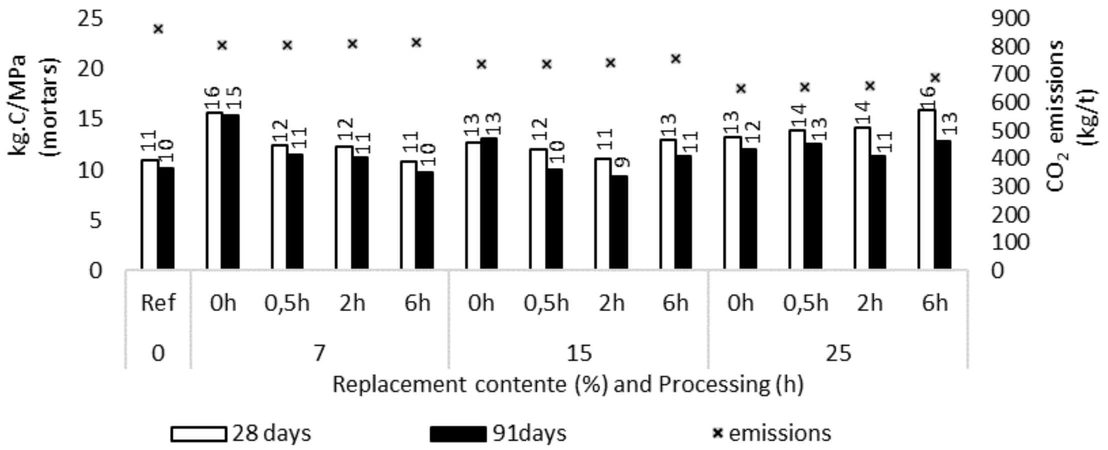


Source: The authors (2023)

3.3 EMISSIONS AND BINDER INDEX

All cement produced (table 1 and figure 6) are less emissive than the reference (CP V ARI), reaching a reduction of around 25% of kg.CO2/t of produced RC cement (25% residue at 0h). The higher the Portland cement replacement rate for treated waste, the lower the associated CO2 emissions per ton of product. The increase in waste treatment time increases CO2 emissions per ton of cement, but this increase does not surpass the emissions from clinker.

Figure 6 - Binder index (kg.C/MPa) and CO2 emissions from RC cement (kg/t)



Source: The authors (2023)

Regarding the binder index, it can be seen in table 1 and figure 5 that the mortars produced with 15% of residue in substitution of Portland cement presented better performance, for the treatment times of 0.5 and 2 hours with 10 and 9.3 kg.C/MPa, respectively. For 25% replacement, results similar to the reference was obtained only after 91 days for the residue treated for 2 hours (11.4 kg.C/MPa). It is suggested that new studies be conducted considering the use of superplasticizer additives, the absorption of water from the waste, and other particle treatment processes. The cement-based matrix with the concrete residue must be evaluated regarding durability.

4 CONCLUSIONS

Cement was produced with concrete residue with up to 25% of substitution to Portland cement. The longer the treatment time, the greater the compressive strength obtained for the three substitution contents evaluated. With 25% substitution, it was possible to produce cement that meet the resistance class C32. With the contents of 7% and 15%, the C40 class was reached. The most significant increase in compressive strength over time occurred at 91 days. Matrices with concrete waste have the potential to mitigate emissions per kg.CO2/t by up to 25%, in addition to reducing binder/MPa consumption by up to 13%. Given the volume of concrete produced annually worldwide and the volume of construction and demolition waste generated, this incorporation is promising to produce less emissive cement.

ACKNOWLEDGMENTS

To CNPq for the Scientific Initiation scholarship to Gabriela Leite. To Unila for promoting research. To the Laboratory of Performance, Structures, and Materials (LADEMA) and the Interdisciplinary Laboratory in Physical Sciences (LICF) for supporting the experimental research.

BIBLIOGRAPHICAL REFERENCES

1. ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 5752: Materiais pozolânicos - Determinação do índice de desempenho com cimento Portland aos 28 dias. Rio de Janeiro: ABNT, 2014.

2. ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 7215: Cimento Portland-Determinação da resistência à compressão de corpos de prova cilíndricos - Especificação. Rio de Janeiro: ABNT, 2019.

3. ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 16605: Cimento Portland e outros materiais em pó - Determinação da massa específica. Rio de Janeiro: ABNT, 2017.

4. ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT NBR 16697: Cimento Portland - Requisitos. Rio de Janeiro: ABNT, 2018.

5. BORDY, A.; YOUNSI, A.; AGGOUN, S.; FIORIO, B. Cement substitution by a recycled cement paste fine: Role of the residual anhydrous clinker. Construction and Building Materials, v. 132, p. 1–8, 2017.

6. CZIGLER, T et al. Laying the foundation for zero-carbon cement: The cement industry is a top source of CO_2 emissions, but abatement pressures could prompt efforts to reimagine the business. Mckinsey e Company, Rio de Janeiro, v. 40, n. 2, p. 9, 2020.

7. JOHN, V. M.; DAMINELI, B. L.; QUATTRONE, M.; PILEGGI, R. G. Fillers in cementitious materials - Experience, recent advances and future potential. Cement and Concrete Research, 1. dez. 2018.

8. PAZ, C. F.; BIELA, R.; PUNHAGUI, K. R. G.; POSSAN, E. Life cycle inventory of recycled aggregates derived from construction and demolition waste. Journal of Material Cycles and Waste Management, 2023.

9. SCRIVENER, K. L.; JOHN, V. M.; GARTNER, E. M. Eco-efficient cements: Potential economically viable solutions for a low-CO_2 cement-based materials industry. Cement and Concrete Research, v. 114, p. 2–26, 2018.

10. SNIC; ABCP. Roadmap tecnológico do cimento. Rio de Janeiro, 2019.

11. WBCSD, W. B. C. FOR S. D. Getting the numbers right project - Reporting CO_2 (GNR Project). Disponível em: <https://www.wbcsdcement.org/GNR-2019/>.