Partial Replacement of Cement by Sewage Treatment Plant Sludge in Eco-Friendly Cement Mortar

Ramiro J. Espinheira Martins
Department of Chemical and Biological Technology
Polytechnic Institute of Bragança
Bragança, Portugal
Laboratory of Separation and Reaction Engineering – (LSRE-LCM),
Department of Chemical Engineering, Engineering Faculty, Porto University

Juliana M. T. de A. Pietrobelli
Department of Chemical Engineering
Federal University of Technology - Parana
Ponta Grossa, Brazil

Thais Theomaris Grabowski
Department of Chemical and Biological Technology
Polytechnic Institute of Bragança
Bragança, Portugal

***Abstract* — Aiming to create alternatives for the disposal of sludge generated in wastewater treatment plants (WWTP) considering the circular economy principles and contributing to the reduction of environmental impacts generated by civil construction, the objective of this work was to evaluate the technical feasibility of the partial replacement of cement in the production of mortars by the sludge produced at the Bragança WWTP. The sludge was characterised, and different methods were used to prepare the sludge for the mortar. The sludge was incorporated by replacing part of the concrete mass of the mortar mixture. The specimens were tested for compressive strength. The specimen with 7% of sludge ash obtained the best result, the specimens with sludge from the drying-only treatments showed a result similar among themselves. The incorporation of the sludge resulted in mortars within the specification of the standard EN 998-1: 2018 and consequently have technical feasibility.**

Keywords—Sludge ash, sludge sun dry, mechanical strength, WWTP.

I. INTRODUCTION

The increase in sludge generation in wastewater treatment plants (WWTP) makes sludge management a difficult task so that it is necessary to create alternatives for the final sludge disposal [1]. The mineralogical characteristics of the sludge allows it to be applied to construction materials [1].

The construction industry is the one that most exploits and consumes natural resources and uses energy intensively, thus generating quite considerable environmental impacts [2]. Creating sludge utilisation techniques in the construction industry provides a safe and stable destination for sludge and contributes to reducing the environmental impacts that the construction industry already has [1], [2].

Thus, the general objective of this project was to evaluate the technical feasibility of the use of WWTP sludge for partial replacement of cement in the production of mortar.

II. METHODOLOGY

For the study, sludge was collected from the WWTP in Bragança, and it was characterised by pH, humidity (HUM), total solids (TS), and organic matter content (OM). The pH determination was based on Embrapa's (1997) soil pH analysis methodology [3]. The determination of HUM and TS was carried out simultaneously based on Standard Methods for the Examination of Water and Wastewater (2005) [4]. To determine the OM content a mass of approximately 250 mg of dry and ground sludge was mixed with 10 mL of 1 N potassium dichromate solution and 20 mL of concentrated sulfuric acid in light agitation and then left to rest for 30 minutes [5]. After this period, 200 mL of distilled water, 10 mL of concentrated orthophosphoric acid and 1% ferroin indicator were generated, which was then titrated with a 0.5 N of ammoniacal ferrous sulphate solution until obtaining a green colour [5]. The blank was performed with the same procedure described above, but without the addition of the sludge sample [5]. The calculation of the OM is given in (1):

$$OM = 1.725 \times (10 - (V2 \times 10 \times V1^{-1})) \times 0.4 / m \quad (1)$$

where OM represents the organic matter content in %, V1 the volume of ammoniacal ferrous sulphate spent on white titration in mL, V2 the volume of ferrous ammonia sulphate spent on the titration of the sludge sample in ml and m the mass of sludge sample analysed in g.

Different methods were used to prepare the sludge for the mortar to study the influence that sludge processing has on the mechanical strength that the specimen acquires. Method 1 (M1): The sludge was dried in a Scientific Series 9000 Laboratory Oven, model 972, at 105 °C for 24 hours [6], [7]. Method 2 and 3: A sludge sample was left in the sun to dry naturally, as in Costa's (2011) [9] work, however for a period of 7 and 15 days (M3 and M4 respectively). In this case the residual unit was determined after the drying period in the sun. Methods 4 (M4): A previous mass dried sludge was burned for

0.5 hour at 300 °C and for 3 hours at 900 °C in a muffle furnace [6], [7].

Mortars were produced with 0 (standard), 3, 5, 7 and 10% replacement of cement by treated sludge. All specimens produced have the same concentration of water and sand, 14% and 54% respectively. The preparation, production and storage of the specimens followed the EN 1015-11:2019 [10].

The mortars were tested on 7-day age of curing and on 28-day age of curing. A mechanical test was carried out on the specimens, the compressive strength. The test was carried out in accordance with EN 1015-11:2019 [10].

Statistical analysis of the compression data was performed. The data were submitted to one-way analysis of variance (simple ANOVA) by Tukey's honestly significant difference (HSD) procedure to compare the means with 95,0% confidence level. Statistical analyses were performed with STATGRAPHICS Centurion software.

III. RESULTS AND DISCUSSION

The sludge characterisation showed that it has a pH of 7.8, HUM of 83.2% ± 0.2%, TS of 16.8% ± 0.2% and OM of 20.7% ± 4.4%. These data show that the sludge has been stabilized non-chemically and has a low organic matter content [1]. The residual humidity of the sun-dried sludge was determined, for M2 5.5% and for M3 4.0%. Fig. 1 shows the final compressive strength obtained by the specimen in each methodology and the homogeneous groups created according to Tukey's test are arranged by the lower-case letters.

*No specimens were produced with 10% M2.

Fig. 1. Compressive strength at 28-day age of curing acquired by the mortar for each treatment and substitution concentration and division of the mortars produced into homogeneous groups (Tukey multi-comparison test, $p \leq 0.05$.

M4 in the concentration of 7% showed higher strength than the standard and the other specimens with sludge ash (M4). In the other concentrations, the incorporation of the sludge ash did not impact significantly on the mechanical strength acquired by the mortar, since they obtained strength very similar to the standard and all are in the same homogeneous group (fg).

The specimens with M1, M2, M3 showed very similarly mechanical strength values and behaviour. In these cases, the strength decreases as the concentration of processed sludge increases. The results for each concentration were very close regardless of the drying process. The combination of the residual humidity data M2 and M3 (considering 0% HUM for M1), the mechanical strength and the homogeneous groups obtained, shows that in the possibility of sludge drying in the sun, there is no variation in the quality of the mortar obtained with the same mortar produced with oven-dried sludge, provided that the system formed contributes to the efficiency of the drying process and that the climatic conditions are favourable.

The variation suffered by standard specimens may be due to changes in cement due to the way of storing bags after being opened, as well as irregularities in the quality of the sand used.

IV. CONCLUSION

From the characteristics of the sludge collected in the Bragança WWTP and the mechanical strength results, the sludge presents great potential to be incorporated into construction materials.

The use of sludge ash in small concentrations does not change the mechanical strength of the mortar, at the concentration of 7% replacement of cement by ash the mechanical quality increases compared to standard mortar. Between sun drying and oven drying, there is no change in the quality of the produced mortar, however, the residual humidity of the sludge to be incorporated into the mortar.

The application of sludge in mortar mixtures represents a good solution for the stable and safe disposal of WWTP sludge.

ACKNOWLEDGMENT

The authors wish to thank Ing. Maria João Almeida Pinto Santos Afonso, João Augusto Pires and Octávio Manuel do Nascimento Pereira for providing technical support to the tests. To the Águas de Portugal group, Águas do Norte, for allowing the collection of sludge for the study. The dual diploma agreement between Federal Technological University of Paraná and Polytechnic Institute of Bragança.

This work was partially supported by the Base Funding - UIDB/50020/2020 of the Associate Laboratory LSRE-LCM - funded by national funds through FCT/MCTES (PIDDAC).

REFERENCES

[1] L. Świerczek, B. M. Cieślik, and P. Konieczka, “The potential of raw sewage sludge in construction industry – a review,” *Journal of Cleaner Production*, vol. 200. Elsevier Ltd, pp. 342–356, 2018, doi: 10.1016/j.jclepro.2018.07.188.

[2] J. M. Paris, J. G. Roessler, C. C. Ferraro, H. D. Deford, and T. G. Townsend, “A review of waste products utilized as supplements to Portland cement in concrete,” *J. Clean. Prod.*, vol. 121, pp. 1–18, May 2016, doi: 10.1016/j.jclepro.2016.02.013.

[3] M. E. C. Claessen, *Manual de métodos de análise de solo (Manual of soil analysis methods)*, 2nd ed. Rio de Janeiro: Copyright, 1997.

[4] L. S. Clescerl, A. E. Greenberg, and A. D. Eaton, *Standard methods for the examination of water and wastewater*, 20th ed. Washington: American Public Health Association, 1998.

[5] T. F. Sampaio, D. M. Fernandes, A. Guerrini, J. C. Bogiani, and C. Backes, “Comparison between methods of organic matter determination in soil samples based on volume or mass,” *Rev. Bras. Ciência do Solo*, no. 2, pp. 517–523, 2011, doi: 10.1590/S0100-06832012000200021.

[6] D. J. R. Sampaio, “Análise da viabilidade técnica da utilização de lama de ETA para substituição parcial de cimento na produção de betão (Análise da viabilidade técnica da utilização de lama de WTP para substituição parcial de cimento na produção de betão),” Faculdade de Engenharia Universidade do Porto, Porto, 2017.

[7] D. Nakic, "Environmental evaluation of concrete with sewage sludge ash based on LCA," *Sustain. Prod. Consum.*, vol. 16, pp. 193–201, Oct. 2018, doi: 10.1016/j.spc.2018.08.003.

[8] Á. J. C. da Costa, "Análise de viabilidade da utilização de lodo de ETA coagulado com Cloreto de Polialumínio (PAC) composto com areia como agregado miúdo em concreto para recomposição de calçadas – Estudo de caso na ETA do município de Mirassol-SP (Feasibility analysis of t," Escola de Engenharia de São Carlos, São Carlos, 2011.

[9] Á. J. C. da Costa, "Feasibility analysis of the use of ETA sludge coagulated with polyaluminum chloride (PAC) compounded with sand as fine aggregate in concrete to recompose sidewalks: case study at the ETA in the municipality of Mirassol-SP," Escola de Engenharia de São Carlos, São Carlos, 2011.

[10] C. E. de N. CEN, *EN 1015-11:2019 - Methods of test for mortar for masonry; Part 11: Determination of flexural and compressive strength of hardened mortar*. 2019, p. 18.