ICSEFCM 2021

Proceedings of the 2nd International Conference on Sustainable, Environmentally Friendly Construction Materials (2021) 27–32
Edited by: E. Horszczaruk, P. Brzozowski

Environmental benefits and mechanical performance of cement mortars with tungsten mining residues incorporation

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CONFERENCE PAPER

Abstract

Secondary mining resources have been largely applied for the development of alternative building products. Additionally, its reuse versatility increases the potential on the future circular economy generation. Herein, mining residues from Panasqueira mine were applied in the formulation of cement-based mortars, according to EN 196-1 standard. Mechanical performance of mortars was analysed after the replacement of the conventional binder (cement) by mining residues in 10, 25 and 50 % (v/v). As expected, compressive and flexural strength decrease when compared to the reference mortar (100 % cement) in all cases. This decrease was more significant in terms of compressive strength (between 27 % and 71 %), when compared to flexural strength results (between 18 % and 56 %). Furthermore, an environmental approach of secondary mining resources incorporation on mortars, regarding Portugal and Poland data, was carried out. The savings in terms of primary resources may promote to minimise energy impacts. When mining residues replace cement in 10 % is possible to save 0.3 or 1.9 Mt of cement production and 0.14 or 0.89 CO_2 Mt emissions, in Portugal and Poland, respectively.

Keywords: Secondary mining resource, Building product, Flexural strength, Compressive strength, Sustainability

1. Introduction

The improvement on building energy performance for saving energy and enhancing sustainability within the construction sector is now on the top list. The growth of urban areas is considered a severe problem as 50 % of the global population lives in metropolitan zones and is foreseen to achieve up to 70 % until 2050. This radical growth will mean the need of additional infrastructure resources to serve the population [1].

A large percentage of current construction products are cement-based (e.g. concrete and some mortars), where concrete has been reported as the second most consumed substance on the world, immediately after water [2]. According to worldwide cement production data, it was estimated that 4.1 billion t of cement were produced in 2018, where clinker production reached ~77.7 million t [3]. Concrete exploration is one of the main contributors of greenhouse gas emissions [4]. Approximately 10 % of the global CO_2 emissions are due to provision of construction materials, where cement accounts for ~85 % [5]. Cement CO_2 emissions mainly come from raw materials mining, firing and product milling processes, which involves energy/fuels and electricity. Shipping also increases CO_2 emissions depending on distances, although it can be considered a stream common to other products [6].

To revert the negative impacts that came up from global emissions, European Commission has set a greenhouse gases reduction up to 40 % (regarding 1990 levels) until 2030, coupled with an energy efficiency improvement of processes above 32.5 % [7]. In addition, the reuse of potential secondary resources towards circular economy targets should be pursued [8].

Mining industries produce high rates of mining wastes once, to access the ore, waste rock needs to be removed and other residues are generated from ores' extraction processes. The accumulation of these residues, namely in open pits, generate critical landscape and other environmental problems. One example is Panasqueira mine, one of the largest tin (Sn) – tungsten (W), that is located in Covilhã, Portugal. Panasqueira mine has been active for more than one century. There are almost 8,500,000 t of tungsten mining wastes in Panasqueira mine area, and ~100 t per day are still being generated due to mining processes [9,10].

Tungsten mining residues have shown feasible reuses in innovative construction products, as part of alkali activated products [11,12] or as pozzolanic material [13], promoting the decrease of mining waste disposal and primary raw materials needs in the construction sector. Thus, it is imperative to pursue new solutions to empower the sustainability of both industrial sectors.

In the present work, cement-based mortars were produced by partially replacing conventional cement content by tungsten mining residues in 10, 25 and 50 %. To increase the add-value of tungsten mining secondary resources, residues from Panasqueira mine (collected directly from the tube output, after the extraction of the mined ores) were applied in cement-based mortars formulation. The mechanical performance of the mortar was studied through compressive and flexural strength tests. Additionally, an environmental approach of mining residues incorporation on mortars production was assessed, regarding Portugal and Poland cement production available data.

2. Materials and methods

2.1 Materials

For mortars formulation, tungsten mining residues were collected from Panasqueira mine sludge circuit (Covilhã, Portugal, 40°10′11″N, 7°45′24″W) and were used as binder together with Portland limestone cement CEM II/BL 32.5 N (Secil, Portugal). Washed siliceous sand (Portugal), with particle sizes mainly between 0.5 and 2.0 mm, was applied as aggregate (Figure 1). Tap water was used to hydrate the formulation.

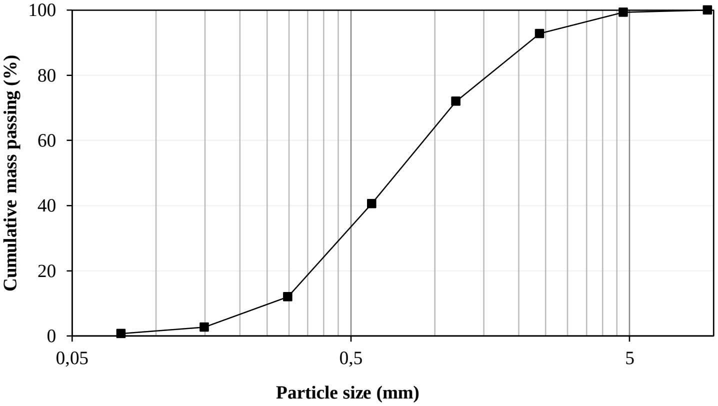


Figure 1. Dry particle size distribution of the sand used in mortar formulation.

2.2 Methods

Mortars were produced based on EN 196-1 [14], considering a volumetric proportion of cement, washed siliceous sand and water of 1:3:0.5 as reference. The reference mortar was produced with 100 % of cement as binder. Mortars were also produced replacing 10, 25 and 50 % of the cement volume content by tungsten mining residues (Table 1). The materials loose bulk density (Cement = 1.00 g/cm^3; Mining residues = 1.18 g/cm^3; Washed siliceous sand = 1.54 g/cm^3) were used to determine the volumes of the components as exact masses. Samples were produced in 40 mm x 40 mm x 160 mm metallic moulds.

Table 1. Quantity of binder, aggregate and water used to formulate the mortars according to the volumetric proportion of 1:3:0.5.

	Binder (1)				**Aggregate (3)**		**Water (0.5)**	
	Cement		*Mining residues*		*Washed siliceous sand*		*Tap water*	
Code	%	g	%	g	%	g	%	g
REF	100	666.7	-	-	100	2000	100	333.3
MR10	90	600.0	10	66.7		2000		333.3
MR25	75	500.0	25	166.7		2000		333.3
MR50	50	333.3	50	333.3		2000		333.3

Following the formulation, the samples were demoulded after 48 hours and left in a water curing for 26 days, at ~20 ºC. Then, the samples were dried at 60 ºC, until achieved a constant weight. The mechanical performance of the specimens was carried out according EN 196-1 [14], considering the analysis of the flexural and compressive strength in a Zwick/Rowell Z050 equipment.

For flexural strength tests, three-point bending test was performed. The loading cell applied was gradually lowered at a constant rate of 50 ± 10 N/s until failure occurred. Flexural resistance (F_r) was determined in MPa, according to equation (1), where F_f is the maximum force (N), l is the distance between the supports length (100 mm) and b the width of the sample (40 mm).

$$F_r = \frac{1.5 \times F_f \times l}{b^3} \tag{1}$$

Compressive strength tests were performed with the half samples disjointed in the previous flexure tests. The loading cell was progressively lowered at a constant ratio of 2400 ± 200 N/s until the mortar failure occurred. Compressive resistance (C_r) was determined in MPa by the quotient of Fc - the critical compressive force (N) - and the cross-sectional area subjected to compression (1600 mm^2).

All sample analysis was carried out in triplicate. Statistical analysis of data was performed with the software GraphPad Prism, version 7.0e. The statistically significant differences between samples for 95 % level of significance were evaluated by ANOVA tests.

3. Results and discussion

3.1 Mechanical tests

Figure 2 shows the flexural and compressive behaviour of all the formulated mortars. Both studied strengths showed a resistance decrease with the increase of the amount of tungsten mining residues incorporation. When 10 % of tungsten mining residues was incorporated in mortars production, it was possible to achieve a mechanical behaviour more similar to the reference mortar (100 % cement binder). However, both compressive and flexural strengths decrease 27 % and 18 %, respectively, in comparison to the REF mortar. Particularly, the flexural decrease may had occurred due to the stress concentrations induced by the filler particles [15], since tungsten mining residues have dissimilar properties when compared to cement. The ratio between cement and washed siliceous sand decrease, promoting the failure to occur sooner, when the load was applied.

Additionally, regarding compressive strength results, mining residues composition include chloride and sulphate contents [16], which may also had affected MR50>MR25>MR10 performance in sequence. Lower amounts of chloride will promote lower potential of corrosion (considering steel reinforced concrete applications), and reduced quantities of sulphates will reduce the formation of expansive complexes, and consequently, cracking issues [17]. Comparing to the REF, MR10 would be the most reliable alternative, regarding coating applications, instead of structural uses, once flexural strength decreases less significantly than compressive strength.

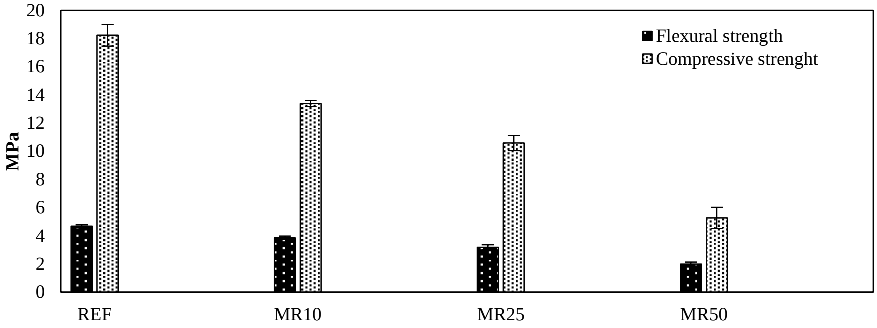


Figure 2. Flexural and compressive strength of the formulated mortars.

All tested mortars flexural and compressive strength results are statically significant different ($p < 0.0001$), corroborating the influence of mining residues incorporation and replacement percentage on the mechanical properties studied. Also, strengths decrease almost linearly with an increase of tungsten mining residues incorporation (Figure 3). The decrease was deeper in the compressive strength case (-1.34 MPa/ mining residues %) when compared to the flexural strength (-1.11 MPa/ mining residues %). The linear tendency was validated by the R^2 determined for flexural (~0.99) and compressive (~0.96) strength.

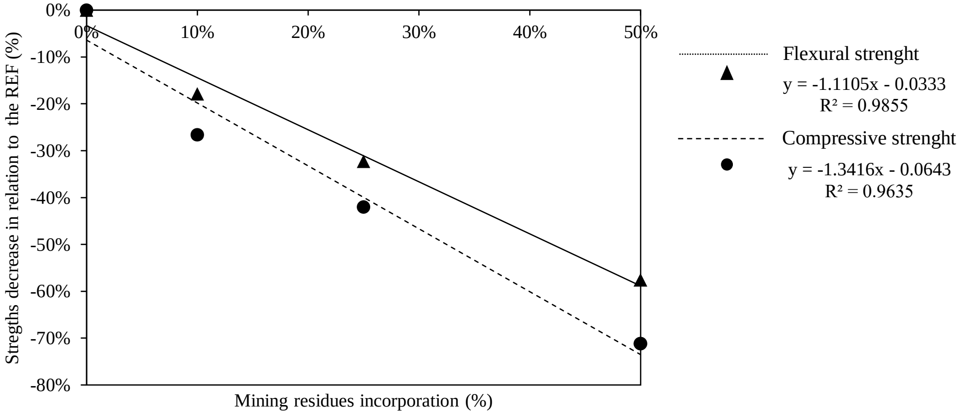


Figure 3. Flexural and compressive strength and mining residues percentage of incorporation in mortars linear tendency.

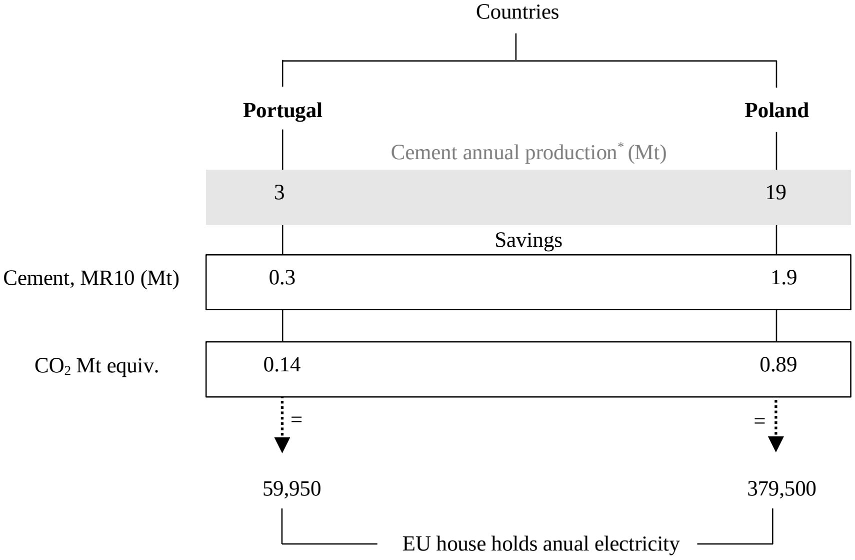
Mining residues properties can be enhanced through different techniques [18]. Electroremediation may decrease salts contents [17] and also other harmful compounds present in the sample [16], while thermal treatment may improve pozzolanic reactivity [19] of mining residues, promoting a larger application of the products within the construction industry.

3.2 Environmental assessment

The incorporation of alternative secondary resources in mortar production may be key factor for waste disposal and energy savings. Figure 4 illustrates how the replacement of 10 % of cement by secondary mining resources may minimize Portugal and Poland cement production issues.

The annual production of cement reported in 2019 for Poland was ~19 Mt [20] and for Portugal around 3 Mt [21]. Considering the formulations tested in the present work with properties more similar to the reference mortar, an approach of cement production savings was determined regarding MR10 case. Thus, having in mind a minimization in 10 % of cement production, Portugal may have savings ~0.3 Mt, while in Poland this value may reach almost 2 Mt, due to its higher production. Also, it will be possible to minimize the same amount of mining waste disposal, respectively.

In terms of carbon footprint, it is reported that the manufacture of 1 ton of cement yields ~0.471 t CO_2 [22]. Assuming this emission impacts, a 10 % lower cement production will promote to decrease an amount of 0.14 CO_2 Mt in Portugal, which is equivalent to ~59,950 EU house holds annual electricity needs (considering that 1 EU house has a carbon footprint equivalent to an average of ~2.35 [23]). On the other hand, in Poland CO_2 emissions may be avoided in ~0.89 Mt, translating in ~379,500 EU house holds annual electricity.



*data from 2019 annual reports

Figure 4. Portugal and Poland approach for cement production and CO_2 equivalents savings considering a cement replacement of 10 % (MR10).

4. Conclusions

Secondary mining resources have high disposal rates and features in terms of raw material, making them particularly attractive for enhancing building products. In the present work, different replacement percentages of tungsten mining residues in the binder content of cement-based mortars were tested to assess its influence on mechanical properties. Coupling cement and tungsten mining residues may also potentiate the decrease of primary resources need, while decreasing associated costs due to its exploitation, namely in industrial scale perspectives.

Higher ratios of tungsten mining waste incorporation in mortars formulation showed influence on mechanical properties in sequence 50 %>25 %>10 %, comparing with a mortar formulated under the conventional method with only cement as binder. In all cases, compressive strength (between 27 % and 71 %) was more affected than flexural strength (between 18 % and 56 %) in the final products, being the formulation with 10 % of cement replacement by tungsten mining residues more similar to the reference (flexural strength = 3.8 MPa; Compressive strength = 13.4 MPa), as expected.

Secondary resources incorporation on cementitious-based mortars may empower the sustainable growth of the involved sectors due to the minimization of waste disposal and CO_2 emissions. Considering an approach in Portugal and Poland, a CO_2 reduction of 0.14 and 0.89 Mt, respectively, was estimated, considering a minimization in cement production of 10 %.

Acknowledgements

This work has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 778045, and European Research Council under grant agreement No. ERC-2016-CoG 725034, as well as from Portuguese funds from FCT/MCTES through grant UID/AMB/04085/2020. J. Almeida acknowledges *Fundação para a Ciência e a Tecnologia* for the PhD fellowship PD\BD\135170\2017. The authors acknowledge Eng. Manuel Pacheco from Panasqueira mine for providing mining residues samples and Eng. Vitor Silva for the help during mortars formulation and analysis.

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