Industrial waste: Study for adding or partial replacement in Portland cement

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ABSTRACT: In an attempt to mitigate the environmental impact of industrial activities and the assumption of scarcity of raw materials due to the impacts experienced in the present world seek out alternatives for recycling of industrial waste generated on macro complex civil construction sector. The objective of this study was to promote a literature review of promising approaches published for introduction of industrial waste for adding or partial replacement of Portland cement. To reach this goal, we carried out a literature search which included: the consultation of selected national and international, conceptualizing the cement in the sector of sustainability and civil construction and, especially, in consultation with the research at national and international levels for characterization of the types of waste as possible to be incorporated in Portland cement. The conclusion was that there is a predisposition of waste red mud and waste of marble and granite to be recycled, with compositions similar to the raw material for the manufacture of Portland cement, having more positive results in physical and chemical analyzes on the wastes that were, according to the authors pozzolanic activities.

Keywords *Industrial waste; Portland cement; Sustainability; Red mud; Ornamental stones.*

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1. INTRODUCTION

Portland cement is one of the main products in the production of concrete since its creation. With the advancement in technology of constructions and population growth have boosted the development of activities in the construction industry and, as a result, the increase in the consumption of cement, which went on to be material more used in civil construction in the world. The production of cement in 2013 revolved around 4 GT per year having a growth of 9% compared to the previous year (Supino *et al*., 2016), the annual per capita consumption of cement in 2009 was approximately 450 kg, with a view to 5 billion tons of consumption in 2050 (WBCSDb, 2009, Battagin, 2011).

However, during the process of cement production requires a high energy consumption and high levels of CO_2 in the atmosphere, especially in the middle phase of production of clinker, in addition to the high consumption of raw material (Aruntas *et al*., 2010, Supino *et al*., 2016). The impacts can be measured in the consumption of around 3% of primary energy used in the world (Juenger *et al*, 2011) in issuing the atmosphere of approximately 2 billion tons of CO_2 (Shi *et al.*, 2011) and the consumption of 1.5T - 1,7T of materials minerals to 1T clinker (Yen *et al.*, 2011, Zang *et al.*, 2013) causing major impacts if there is no sustainable change in the production process.

Despite the difficulties of introducing new materials in the construction industry to be characterized as a traditional sector, discussions and the needs around sustainability drives the changes in the production process of Portland cement with the deployment of waste as by-products in the promise of reducing environmental impacts in the emission of gases and contamination of the environment, consumption of raw materials, the costs with outlets and the enhancement of the qualities of concrete (Tsakkiridis *et al*., 2004, Juenger *et al*., 2011). Recent studies have demonstrated that the use of industrial waste as raw material, bring economic benefits, technological, environmental, and the civil construction industry a potential for receiving various types of waste (Ribeiro *et al*., 2011, Pontikes & Angelopoulos, 2013).

The cement industry in order to contribute to the sustainable development has assumed major challenges in improving waste management operations (Shi *et al.*, 2011). An example of this advance was the creation, in the late 1990's, by the main companies of cement, Cement Sustainability Initiative (CSI), composed of members of the Program World Business Council for Sustainable Development (WBCSD), in order to identify and explore sustainable actions in the cement industry (Schneider *et al*., 2011, Supino *et al*., 2016). The producers of cement moved to review the methods and materials for the production of cement began to search for studies for introduction of new raw materials more economical and abundant (Yen *et al*., 2011).

In this context, the large volume of industrial waste deposited in landfills, as a result of industrial growth and urbanization, emerges as shaft to replace the natural raw material in the production of Portland cement contributes to reduction of environmental impacts in both industries (Metha, 2001, Neeraj, 2011). It is observed that many of these materials industries have undesirable in its composition significant levels of inorganic materials, such as oxides of silica and aluminum that in appropriate mixtures can be used in the production of Portland cement by improving their physical characteristics and mechanical properties

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as the workability and resistance and next to that contribute to reducing the environmental impacts of the cement industry to Environment (Tsakkiridis *et al*., 2004, Neeraj, 2011).

The introduction of industrial waste in production and substitution of cement has three sustainable basis, not only helping in reducing the use of natural raw materials and the recycling of waste from other industries, as well as, contributing to a reduction in CO_2 emissions and energy consumption to reduce the firing time of the clinker (Zhang *et al*., 2013, Aliabdo *et al*., 2014).

The objective of this study is to promote a literature review of promising approaches published for introduction of industrial waste for adding or partial replacement of Portland cement. The analyzes were concentrated in the residues of the aluminum industry - the red mud and in the processing of ornamental stones of marble and granite, due to the high volume in disposal of waste in these industries in the production steps, exposing the technical, environmental and mechanical when it incorporates waste in the cement industry.

2. OVERVIEW OF CEMENT PRODUCTION

It estimated that every year the ratio between the production of concrete per person in the world reaches $1m^3$ (Akalin, 2014). Portland cement is the main hydraulic components for the production of concrete containing 12% of the material in its composition that means approximately 1.6 billion tons of cement consumed by industry of the concrete in the world (Mehta, 2002). The production of cement in dry process (greater spread) is basically the process of crushing, grinding, drying and mixing of limestone and clay, rich in silica (SiO_2), calcium (CaO), aluminum (Al) and iron oxide (Fe_2O_3) forming a raw flour. This flour is brought to a rotary kiln to 1450ºC formed a hydraulic material cementitious called clinker. The clinker cooled and added to a small portion of plaster (approx 5%) and other additives forming the cement (WBCSDa, 2009, Usón *et al*., 2013).

The average percentages of the composition of the clinker shown in table 1 are the basis to be reached by alternative raw materials to be added.

Table 1. The chemical composition of the clinker in the dry process.

Composto	%
CaO	65 (+- 3)
SiO2	21 (+-2)
Al2O3	5 (+- 1,5)
FeO3	3 (+-1)

Source: Madlool *et al. (*2011), Usón *et al. (*2013).

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3. ANALYSIS OF INDUSTRIAL WASTE

This study presents the industrial waste produced, deposited in landfills, with a considerable degree of environmental impact, emphasizing the red mud and debris of marble and granite.

3.1. Generation and characterization of residual bauxite (red mud)

The industry of iron ore producer of aluminum and alumina deposits worldwide, approximately 66 million tons of waste, known as red mud (Tsakiridis *et al*., 2011, Zhanga *et al*., 2011). The red mud is discarded during the process of Bayer, the mixture of bauxite with sodium hydroxide, in ratio of about 1,0T to 1,6T of mud per ton of aluminum produced (Tsakkiridis *et al*., 2004, Ribeiro *et al*., 2011, Zhanga *et al*., 2011).

Has the physical characteristics such as fine particles (<10μm), high specific surface (13-22m²/g), release of OH- ions in the mix with water, high rate of alcanilidade (10 - 13,5 pH) that can impact the environment requiring forms of restricted discard (Ribeiro *et al*., 2011, Senff *et al*., 2011). The residue is pumped into holding tanks, where they are deposited in large dams with areas of approximately 200 acres, in which occurs the natural sedimentation of the solid phase (Silva Filho *et al*., 2007, Wanchao *et al*., 2014).

The application of bauxite residue in addition or partial replacement of cement emerges as a possibility for exploratory analysis, as presented in item 4.1. The methods to incorporate this residue can occur in two ways: in flour raw or as a hydraulic material or pozzolanic. In flour raw, it is usual to source of Fe and Al and the final product may be Portland cement, or other type of cement compound with the addition of the residue. As material applied hydraulics in a matrices cementitious, the bauxite residue becomes a reactive component, may develop pozzolanic reactions (Pontikes & Angelopoulos, 2013).

The chemical composition of red mud varies according to the nature of bauxite and technological processes in each industrial process (Tsakkiridis *et al*., 2004, Silva Filho *et al*., 2007, Ribeiro *et al*., 2011, Senff *et al*., 2011, Pontikes & Angelopoulos, 2013). The chemical composition of the residue consists mainly of Fe_2O_3, Al_2O_3, TiO_2, SiO_2, CaO and Na_2O as shown in table 2.

Table 2. Chemical composition of waste red mud

Compost %	(Tsakiridis *et al*., 2004)	(Ribeiro *et al*., 2010)	(Zhanga *et al*., 2011)
SiO2	6,8	14,34	18,0
Al2O3	19,95	19,87	6,31
FeO3	40,8	19,85	12,38
CaO	12,6	4,61	35,09
MgO	0,2	0,21	1,13
K2O	0,14	1,87	0,45
Na2O	2,7	7,35	2,71
LOl	10,54	27,2	20,07
SO3	0,58	-	0,54
TiO2	5,8	2,66	3,32

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3.2. Generation and characterization of waste processing plants of ornamental stones (marble and granite)

Many countries such as India, Egypt, Brazil, Italy and Spain have different processing industries in marble and granite scattered throughout your territory. Mashaly *et al*. (2016) point with the most important industrial activity in the whole economy in the world. Due process of disposing of waste at different stages the industries of marble and granite contribute significantly in environmental problems (Aliabdo *et al*., 2014).

The figures on the amount of disposal in landfills are alarming. In India, for example, about 6 thousand tons/year of waste from the dust of marble from the processes of unfolding, polishing, cutting and finishing are discarded (Aliabdo *et al*., 2014). In Brazil, this amount is 190 thousand tons/year of mud of ornamental stones - marble and granite (Barcaji *et al*., 2013).

The process of milling especially in the sawdust from the plates, which is usually done by looms, 20 to 30% of mass of the block is converted into mud and deposited in landfills (Barcaji *et al*., 2013, Mashaly *et al*., 2016).

The residues of the industry of marble and granite can be characterized as material type fillers or pozzolanic, which will be determined as testing. The chemical composition of the waste is characterized by presenting high content of CaO (marble) or SiO2 (granite) as shown in table 3 (Neeraj, 2012, Aliabdo *et al*., 2014). These compositions indicate that there is a potential applicability of these residues in cementitious arrays, either in addition or in partial replacement of Portland cement.

Table 3. The chemical composition of the waste of marble and granite

Compost %	Residue of marble (Aruntas et al., 2010)	Residue of marble (Neeraj, 2012)	Residues of marble and granite (Barcaji *et al*., 2013)			Residue of marble (Aliabdo *et al*., 2014)	Residue of marble (Mashaly et al., 2016)
SiO2	0,67	3,01	58,67	54,62	54,1	1,12	0,15
Al2O3	0,12	1,9	11,26	9,7	10,28	0,73	0,10
Fe2O3	0,08	0,8	7,59	5,86	7,26	0,05	0,04
CaO	54,43	30,8	6,13	12,99	11,27	83,22	55,32
MgO	0,59	19,27	2,96	3,22	1,72	0,52	0,11
K2O	-	-	2,9	0,35	3,94	0,09	0,01
Na2O	0,14	-	2,74	2,15	2,84	1,12	0,07
LOl	43,4	40,4	5,99	9,57	7,84	2,5	43,40
SO3	-	-	0,04	0,02	0,02	0,56	0,13
CaSO4	-	-	0,07	0,03	0,03	-	-

4. ANALYSIS OF THE INTRODUCTION OF WASTE

This review was conducted an analysis of the study of some papers presented in tables 2 and 3, on top of your goals, experiments and conclusions. It is possible to observe the variability of forms of introduction of waste, either in the composition of the clinker, the replacement of cement, and/or in compositions with other waste.

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4.1. Analysis of the use of the residue of red mud

Tsakiridis *et al*. (2004), Investigated the possibility of using the waste red mud with substitution of 3.5% as raw material for the production of clinker in cement Portland, interrupting the hydration at ages 2, 7, 28 and 90 days.

The results presented showed that the incorporation of residue remained the main characteristics of the clinker, there was no change in their mineralogical composition and neither changes in the processes of hydration. In addition to occur an increase in compressive strengths. In this way, the authors conclude that the residue of red mud from the process of manufacturing of aluminum can used as a raw material in the production of Portland cement contributing to the reduction of the cost of the process.

Ribeiro *et al*. (2010), studied the influence of the addition of red mud on the characteristics of the mortar of cement, without thermal treatment of waste, by replacing 50% of the content of cement per residue.

The results of chemical analyzes and mineralogy as well as electron microscopy showed that the use of red mud did not affect the mineralogical characteristics of the clinker of Portland cement. However, the mechanical resistance had a fall to the extent that increased the percentage of addition of red mud, but still suitable for applications not structural. The non-thermal treatment of waste required less energy and time (Ribeiro et al., 2010) making the process more sustainable.

Zhanga *et al*. (2011) based on investigations on the techniques of thermal activation of the red mud to evaluate the feasibility of mixtures of red mud derived from the method of roasting of bauxite with other industrial waste for use as a material cementitious. Working with maximum of 30% of red mud-burned, 21% of slag from blast furnace, 10% of fly ash, 30% of clinker, 8% of plaster and 1% other agents, working with a water/cement of 0.50 with ages tests to results the compression resistance of 1, 3, 7 and 28 days.

The results presented here confirm the usefulness of the mixture based on physical and mechanical properties, the products of hydration predominate observed were the crystals of ettringite and gel of calcium silicate hydrate (C-S-H) amorphous, responsible for the development of resistance in the initial stage of hydration. The objective of this study was to evaluate the replacement of up to 61% of the raw materials for the production of cement, mitigating environmental pollution and reducing the cost in the production of cement (Zhanga *et al*., 2011).

4.2. Analysis of the use of the residue of marble and granite

Aruntas *et al*. (2010), proposed the research for the use of residual dust of marble as an additive in step of grinding of clinker in the production of Portland cement compound, determining its performance. The levels presented in addition vary from 2.5%, 5.0%, 7.5% and 10% with ages for the test of resistance to compression of 7, 28 and 90 days. The results presented by Aruntas *et al*., (2010), show that in all ages the in compressive strength has increased, in its analysis the value great for adding residue is of 10%, which reduces 7.5% the amount of clinker, reducing the cost of production and the impacts to the environment.

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Neeraj (2012) performed a comparative study between the residues of dust of marble - nonpozzolanic, and rice husk ash – pozzolanic, as mineral additions in common cement Portland, analyzing the characteristics of time of setting and compressive strength. The additions with other minerals were made in the levels of 20%, 40% and 60% of dust of marble and 10%, 20% and 30% of rice husk with respect water/cement ranging from 0.30 to 0.38 with ages of testing for resistance to compression of 1, 3, 7, 28, 90, 180 and 360 days.

The results of the samples with mixtures of the residue of marble floor showed that adding influence on behavior, functioning as an accelerator of hydration. As for the mechanical properties, the incorporation of the residue decreased the resistance as the increase in the percentage of addition. This is due to a concentration of CaO, who did not participate in the process of hydration, because it acts as fillers. The author concludes as percentage great increase of 20% in mineral mixtures of residues of dust of marble and 20% of residues of rice husk to the development of Portland cement with a reduction in the use of natural resources and the final cost of the product (Neeraj, 2012).

Barcaji *et al*., (2013), approach the chemical analysis and mechanical performance of the residue of marble and granite, through tests of resistance to compression, modulus of elasticity, water absorption and particle size distribution, in compositions in replacement of Portland cement and its effect on the performance of the concrete. The levels of replacing ranged between 5% and 10% and 20% with respect water/cement from 0.50 to 0.65 and ages tests of 7, 21 and 28 days.

According to the authors, the residues of marble and granite analyzed have not pozzolanic, working as fillers, leading to a reduction in the resistance to compression and modulus of elasticity, affecting the compression ratio of the folder with the household. Through consistency tests showed an improvement in the workability of the material with the addition of the residue and an increase of around 0.9% in the absorption of water. Despite the decrease in resistance the authors claim that can be used containing great for adding 5% by presenting a lower impact on the mechanical properties and rheological properties, and be a model promising in sustainable issues (Barcaji *et al*., 2013).

Aliabdo *et al*. (2014) investigated the possibility of using waste of mud from processing of marble as fat replacement in cement and in a second step for replacing the cement or sand in the production of concrete. The relations of replacing studied were 0.0%, 5.0%, 7.5%, 10.0% and 15% by weight. The ratio of water to cement or reason (a/c) were 0.50 and 0.40 in the case of replacing cement. Were investigated the physical, mechanical and chemical properties.

As a result they obtained that substitution of residue in the cement little influence in settings of the start and end time to handle, however influence in increasing the compression force and the production of a concrete less porous, having a great replacing dust of marble in the cement and sand up to 15% affecting positively the characteristics of concrete. Aliabdo *et al*. (2014) at the end of the experiment concluded that the use of the dust of marble for a surrogate for seating in the concrete has most significant effect on the mechanical properties of concrete.

Mashaly *et al.* (2016) studied the use of residues from the mud of processing of marble as a substitute of cement to 40% and evaluated the production of blocks of paving of concrete.

The proportions were 0%, 10%, 20%, 30% and 40%. Studies conducted mineralogical, physical and mechanical properties of both fresh concrete and hardened. Were determined 3, 7 and 28 days of curing the composite of cement and 28 days for concrete products.

The results showed that the introduction of residual dust of marble enhance the physical and mechanical properties of the materials cementitious, arriving at a great replacement of up to 20% of the mud of marble. They observed a reduction in water absorption, increased density of concrete, improvement in compressive strength and abrasion resistance increased (Mashaly *et al.*, 2016).

5. CONCLUSION

The analysis of the studies presented show that both add as a substitution of residue in a matrices cementitious promote physical improvements and chemical compounds, related to increased resistance, decrease in the levels of water absorption and porosity, and the increase of the density and resistance to abrasion.

The residues identified by authors with characteristics for pozzolanic activities obtained better results in physical and chemical analyzes, in relation to the waste considered not pozzolanic, indeed fillers.

However, due to variability in the chemical composition of the waste as production process and place of landfill, the standardization in relation to percentage great is hindered, being observed values of adding and replacing non-uniform.

Studies to identify the percentage great to be added or replaced of the residue in the manufacturing process of the cement has great relevance and succinctly the exploratory studies in this line, seen identify and support what is being researched and found at matrices cementitious.

There is a need for dissemination of studies of red mud and residues of marble and granite in composition of production or replacement of Portland cement, in order to analyze all or possible ways to chemical, physical, environmental and economic benefits for this type of addition.

As well as the need for studies that lead the connection between the additions and partial replacements of types of industrial waste in Portland cement with a real reduction in economic terms and levels of environmental impacts in order to advance in subsequent steps of commercial introduction of the residue in the production of cement and concrete.

The occurrences of substitution of residue in the production process of Portland cement, from the perspective of sustainability, is more powerful that the application of the residue as addition or partial replacement of cement, by virtue of the reduction of the emission of CO_2, by allowing the reduction of burning time by reducing the consumption of raw material and reduce the cost of production.

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