Impact of Using Bauxite Residue in Microconcrete and Comparison with Other Kind of Supplementary Cementitious Material

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Abstract

The use of bauxite residue (BR) in association with Portland cement may be an alternative for a large-scale application for the waste. With this strategy, would be possible to reduce both environmental impact (cement – large CO_2 released, and alumina/aluminum production). In works related to this research, it was proved that the hardened properties are not deteriorated by using BR, even with reduction in the binder consumption, because the large amount of silica, aluminum and iron, and the physical properties of BR, can affect the hydration reaction, potentializing the use of cement. However, the high sodium content can be a problem due to the potential of leaching after hardening. Additionally, a comparative evaluation between BR and other kind of supplementary cementitious material (SCM) frequently used in association with Portland cement, is still poorly explored in literature. This work was carried out to evaluate the properties of microconcretes formulated with bauxite residue (dried or calcined at 800°C) and to compare with products with silica fume, metakaolin, limestone filler and ground blast furnace slag. The results indicate that BR do not deteriorate the hardened properties of evaluated products, and there are no losses comparing with the other kind of SCM.

Keywords: Microconcrete, bauxite residue, silica fume, metakaolin, blast furnace slag.

1. Introduction

The United Nation (UN) estimates that up to 2050 the population on the planet will be around 9.6 billion of people, with a projection of 10.9 billion by 2100 [1]. However, other organizations [2] estimate 8.7 billion by 2050, dropping to about 8 billion by the end of the century. Regardless of such controversy, the fact is that the population should grow from just over 7 billion today, in an increasingly urban infrastructure than the estimated 54% of people living in cities on this date, reaching 66% by 2050, meaning an addition of 2.5 billion people to urban areas.

Thus, it can be said that there is a clear need to expand the urban places to follow the population growth, and there is still, a huge deficit of housing and infrastructure, particularly in the developing countries. To illustrate this fact, around 90% of the current urbanization process takes place in Africa, Asia, Latin America, and the Caribbean [3], requiring the construction of more than 70 million new urban homes per year. This scenario, which is independent of economic crises, elevates the society's great challenge for more sustainable growth in an era when the natural resources are headed for depletion if the current patterns of exploitation, consumption, and waste generation will be maintained [4].

Another relevant aspect of this analysis is that the aging of world's population will increase in percentage in the next decades (it is estimated that about 21.1% of the population will be over 60 years old in 2050, as opposed to 11.7% in 2013) [1], reducing the economically active workforce in a more populated and urbanized world.

Consequently, there should be an increase in the use of more advanced technological solutions, resulting in more efficient production processes, with a greater degree of automation and less labor intensive, including construction. So, it can be affirmed that there is a clear tendency to world with growing demand for more efficient and productive solutions of construction, with smaller environmental impacts. Therefore, these assumptions must be considered in the design of the future of building materials.

The modern society has in Portland concrete the most produced and consumed material in the world, being estimated a production of more than 10km³/year. Basically, these cementitious products consist of the mixture of aggregates, binder and water and, although it is not possible to obtain an exact value for the volume produced, the volume quoted above is estimated considering the production of Portland cement. In this case, this hydraulic binder reached the expressive mark of 4 billion tons/year between 2013 and 2014, with growth prognosis of 2.5 times by 2050 [5].

It is true that in the modern world, the environmental impacts cannot be tolerated in the same proportion as the increase in the production of cement materials, and that the technologies for producing such materials will be charged to achieve efficiency levels that guarantee high productivity with reduced efforts to the workers.

Regardless of this, the main challenge for the future will be: *how to increase production of the most important building materials to meet the demands of population growth, aging and urbanization, without accentuating the impacts of the enormous volumes produced*?

Considering only the aspects related to materials, different routes have been developed to replace clinker as the use of alternative materials, generally obtained as: i. by-product from industrial process (like ground blast furnace slag, fly ash, silica fume, etc.), ii. inert material (like filler), iii. new kind of cement with lower environmental impact, and others. For this reason, the level of efficiency currently practiced in cement technology has been investigated in order to identify new opportunities to increase the production without increasing the cement production.

Without giving up any of the initiatives presented to reduce environmental impacts on cement production, strategies to reduce the use of binders in formulations have the potential to increase the production of cement materials without the need to increase cement production at the same rate. So, it is possible to infer that to obtain a more eco-efficient scenario it is needed to look for new supplementary cementitious materials (SCMs), to improve the understanding of the characteristics of the currently known SCMs and to evaluate in greater depth the physico-chemical interactions with the different types of binders.

On the other hand, another great environmental challenge is to find a large-scale application for bauxite residue, generated in the Bayer process to obtaining alumina. In this process, the bauxite ore is crushed and milled, heated at a temperature of up to 200°C, in a pressure vessel along with a sodium hydroxide solution; the solution of aluminum-rich components follow in the process, while the residue is separated by filtering, and disposed into the lakes of mud, being hazardous environmentally because of its alkalinity. Despite some controversies, and even with the precise control of lake contention, always will have the risk of disruption, like that occurred in October 2010 in Hungary, killing ten people, and contaminating a large area [6].

4. Conclusions

The use of bauxite residue in association with Portland cement do not deteriorate the hardened properties of microconcretes: comparing the results with other kind of supplementary cementitious material, in general, the characteristics of microconcretes were statistically similar. The mechanical strength of microconcrete with bauxite residue were around 10% less than the reference, but this is not a problem because the products developed in this work presented a great eco-efficiency, i.e.: high compressive strength associated with low binder consumption (binder intensity ≈ 3 kg/m³/MPa).

Air-permeability of microconcrete with calcined bauxite residue was lower than the reference and statistically similar to silica fume, limestone filler and blast furnace slag. The composition with metakaolin was the most permeable followed by the composition with bauxite residue. This parameter presents a closer relationship with durability, because controls the penetration of aggressive agents into the concrete and, in general, the easier the penetration of such agents, the faster the degradation of the cementitious product.

Different from the other kind of supplementary cementitious materials, the microconcrete with bauxite residue, in nature or calcined, presented a little expansion, indicating that it is a shrinkage compensator, and there was not observed any difference about carbonation in function of kind of SCM.

According the results obtained, is clear that it is possible to use this residue in cement compositions, but is still necessary to evaluate the parameters associated to leaching.

5. References

1. Demographic components of future population growth. At <www.un.org>
2. World population could peak by 2055. At. <www.nytimes.com>
3. Global activities Report 2013 – Our Presence and Partnerships. At. <www.unhabitat.org>
4. Limits to growth was right, new research shows we’re nearing collapse. At. <www.wealthydebates.com>
5. Bruno Luís Damineli, Concepts by formulation of concretes with low binder consumption. Thesis (PhD). Escola Politécnica da Universidade de São Paulo. Departamento de Engenharia de Construção Civil, 2013, 237p. (*in Portuguese*).
6. Caio Cesar Liberato et al. Effect of calcination of bauxite residue on the rheological properties and hardened state of Portland cement pastes. *Ambiente Construído* (Online), Vol. 12, (2013), 15-25 (*in Portuguese*).
7. Roberto Cesar de Oliveira Romano, Evaluation of the physico-chemical interactions between bauxite residue and Portland cement. Post-Doc Report. FAPESP – Research Grant – 2012/19262-2 (2016).
8. C. Klauber, M. Gräfe and G. Power. Bauxite residue issues: II. options for residue utilization. *Hydrometallurgy*. Vol. 108, (2011), 11–32.
9. Y. Pontikes, P. Nikolopous and G.N. Angelopoulos. Thermal behaviour of clay mixtures with bauxite residue for the production of heavy-clay ceramics. *Journal of European Ceramic Society*. Vol. 27, (2007), 1645–1649.
10. M. Singh, S.N. Upadhayay and P.M. Prasad. Preparation of special cements from red mud. *Waste Management*. Vol. 16, (1996), 665 – 670.
11. M. Singh, S.N. Upadhayay and P.M. Prasad. Preparation of iron rich cements using red mud. *Cement and Concrete Research*. Vol. 27, (1997), 1037–1046.

12. Roberto Cesar de Oliveira Romano et al., Influence of dispersion technique in the properties of silica fume, *Cerâmica*. Vol. 54, No. 332, (2008), 456–461. (*in Portuguese*)
13. Roberto Cesar de Oliveira Romano, Monitoring of Hardening of Portland Cement Suspensions by Vicat Test, Oscillatory Rheometry, and Isothermal Calorimetry. *Applied Rheology*. Vol. 27 (2017) 36006.
14. ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). NBR 7215: Cimento Portland - Determinação da resistência à compressão, 1996. 8p.
15. ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). NBR 15630/08: Argamassa para assentamento e revestimento de paredes e tetos – Determinação do módulo de elasticidade dinâmico através da propagação de onda ultra-sônica.
16. Gorge Andres Bannura Salvador, Optimization of fine aggregates granulometric distribution for use in rendering mortar in Sant'ana do Livramento – RS. Thesis (MSc). 2005. (*in Portuguese*).
17. Silvia Maria Santos Selmo, Finer aggregates to rendering mortars. In: Simpósio Nacional de Materiais de Construção: Agregados. 1986. São Paulo. pág. 27 – 43. (*in Portuguese*)
18. Roberto Cesar de Oliveira Romano, Air incorporation in cementitious materials applied in civil construction. Thesis (PhD). Escola Politécnica da Universidade de São Paulo. Departamento de Engenharia de Construção Civil. 2013. 200p. (*in Portuguese*).
19. Murilo Daniel de Melo Innocentini et al., Permeability optimization and performance evaluation of hot aerosol filters made using foam incorporated alumina suspension. *Journal of Hazardous Materials*. Vol. 162. (2009). p.212 - 221.
20. Tahir Gonen and Salih Yazicioglu, The influence of compaction pores on sorptivity and carbonation of concrete. *Construction and Building Materials*. Vol. 21, No. 5, (2007), 1040–1045.
21. Christian Varhen et al, Effect of the substitution of cement by limestone filler on the rheological behaviour and shrinkage of microconcretes. *Construction and Building Materials*, Vol. 125, (2016), 375–386.
22. R. Wassermann, A. Katz and A. Bentur. Minimum cement content requirements: a must or a mith? *Materials and Structures*. Vol. 42, No. 7, (2009), 973–982.
23. Ravindra Dhir et al., Role of cement content in specification for concrete durability: cement type influences. *Proceedings of the ICE-Structures and Buildings*. Vol. 157, No. 2. (2004), 113–127.
24. Sandor Popovics. Analysis of the concrete strength versus water-cement ratio relationship. *ACI Materials Journal*. Vol. 87, No. 5, (1990), 517–529.
25. B. Bissonnette, P. Pierre and M. Pigeon. Influence of key parameters on drying shrinkage of cementitious materials, *Cement and Concrete Research*. Vol. 29, (1999), 1655–1662.
26. Alessandra Lie Fujii et al. Impact of superplasticizer on the hardening of slag Portland cement blended with red mud. *Construction and Building Materials*. Vol. 101, (2015), 432–439.
27. Roberto Cesar de Oliveira Romano et al., Monitoring hydration of ordinary Portland cement with bauxite residue. *Cerâmica*. Vol. 62, (2016), 215-223. (*in Portuguese*).