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Non Peer-reviewed author version

MULTIDISCIPLINARY STUDY ON SUSTAINABLE PHOSPHOGYPSUM RECYCLING AND MANAGEMENT

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Introduction

Phosphogypsum (PG) recycling in construction presents a multidisciplinary challenge that integrates technical, radiological, chemical and stakeholder perception related aspects. Annually only 60-80 million tonnes of the produced 215 million-ton PG is being recycled and in particular the recycling of the very heterogeneous PG present in landfills presents an important research challenge. Originating from the processed ore and the production process used, remnants of phosphoric acid, problematic metals, fluorides, organic substances, rare earth elements, and enhanced concentrations of naturally occurring radionuclides can be present in PG and the relatively low recycle rates can be attributed to their presence. [1]

Portland cement (PC) is produced worldwide in large volumes and its large-scale water and energy intensive production can be accompanied by the use of substantial quantities of natural resources. The carbon footprint, primarily originating from the fuel combustion and limestone decomposition, amounts to around 10 % of global CO_2 emissions (0,8 t CO_2 per tonnes clinker). Alternative cementitious binders are under research aimed at enabling the recycling of industrial residues, to achieve a less energy-intensive production process and realising a lower carbon footprint. Although, in some cases an energy intensive pre-treatment step is required for the recycling of the industrial residues and a lower carbon footprint is not achieved.[2]

PG could replace gypsum in PC and alternative cementitious binders. However, depending on the binder type, the mechanical properties (e.g. delay in setting time, reduction in workability or strength) could be negatively impacted by traces of phosphoric acid, fluorides, metals, naturally occurring radionuclides, rare earth elements or organic substances. Depending on the properties of the PG used for recycling suitable treatment procedures need to be implemented. In addition, it is

important to consider the environmental impact and the exposure of workers processing the PG from the landfill or producing the construction materials.[2]

A broad spectrum of research papers (recent review see in reference [3]) is focussing on investigating the technical properties of recycling of PG in new types of cementitious binders while far less research focussed on the non-technical aspects of recycling in particular on the perception of stakeholders that can strongly determine whether or not a particular recycling practice is viable. To address this research gap, the current study provides insight in the multidisciplinary factors influencing PG recycling in alkali activated binder and concretes. Next to technical properties of the PG based binders, worker safety and environmental (radiological and leaching studies) properties, the current study provides a socio-economic study on NORM related stakeholder perception and acceptance targeting the industrial landscape and end-users.

Materials and methods

The current study is a part of two overarching research projects: the King Baudouin Foundation project 2020- 82141050-218715 and the H2020 project RadoNORM.

Technical and environmental impact study: The development of alkali-activated binders based on IAEA reference PG (reference material nr 434) phosphogypsum and ground granulated blast furnace slag (GGBFS), procedures used for mechanical and physico-chemical characterisation (strength, mineralogy, microstructure, porosity…) and environmental impact assessment (leaching study) are described in [4], [5],[6] and [7]. The presence of naturally occurring radionuclides originating from ^{238}U and ^{232}Th decay chains and ^{40}K was determined via a HPGe detector next to dedicated radon exhalation/emanation measurements as described in [4].

Stakeholder perception and acceptance study: Stakeholder perceptions were explored through semi-structured interviews with 13 representatives from the concrete industry in Belgium, allowing for studying more systematically the concerns of the Belgian concrete industry regarding the use of NORM contained residues in cement/concrete. The research methodology used for the qualitative stakeholder perception study is described in [8].

Results and discussion

Technical and environmental impact study

An overview of the chemical, radiological, mineralogical characterisation results of PG from literature and recent characterisation studies is provided.[4,5,7] A large (ore and process depending) variability in the chemical/ mineralogical/radiological properties of

PG origination directly from industrial processes and landfills can be found. Average activity concentration indices for PG range from 0.12 - 3.61.[10] An expanded set of PG based AAM binder formulations was produced and the impact of PG incorporation on the mechanical properties is reported.[7] AAMs incorporating 20%wt PG with compressive strengths up to 20 MPa were produced. By life cycle analysis it was demonstrated, for the production of mortar, that using PG as alternative binder can lead to reduction of up to 30 % in energy demand and up to 57 wt.% CO_2 emissions in comparison to traditional cement-based building materials.[11]

Stakeholder perception and acceptance study

Based on a systematic interview analysis, that is described in depth in [8], the NORM aspects of the multidimensional challenge that cement and concrete producers are facing connected to clinker substitution and the transition to cementitious binders based on industrial by-products was considered in more depth. Via the interview analysis six fundamental challenges related to the transition to a more circular clinker production system were identified by the participants of the study. These themes are (1) availability of the by-products, (2) Financial factors, (3) Quality and performance, (4) Standardised sustainability parameters, (5) Customer demand and (6) Acceptance of NORM-contained by-products.

Theme 1, availability of by-products: In the semi-structured interview, participants indicated that the instability in the local supply of by-products over time can constitute an important barrier for commercial application of alternative, by-product based, binders. When by-products originate from outside Europe the CO_2 emissions related to transport can play a cardinal role and the companies participants highlight the need for regulatory certainty on import regulations to assure a fair competition.

Theme 2, financial factors: Study participants indicate that existing low CO_2 prices do not constitute a strong enough driving force to stimulate companies in investing in new production technologies which can result in companies sticking to existing technology and combining this with options for carbon capture. Participants indicate that the governmental pressure (e.g. via CO_2 taxes) on companies to become greener is limited. While, the high investment requirements result in active lobbying from the industry to avoid an increased governmental pressure.

Theme 3, Quality and performance: Participants indicate that the slow introduction of new types of cement is related to the need to meet strict regulations and standards on quality and performance (that are not harmonised across the EU) and the associated certification requirements. A need for more balanced product regulations accommodating sustainability in the binder development while assuring product safety was identified.

Theme 4, standardised sustainability parameters: Participants argue that the lack of standardised sustainability parameters based on specific environmental parameters while not considering/neglecting other environmental parameters that might even by increased by the new 'greenwashed' practice. In the Netherlands a more recognised, standardised calculation method, the Environmental Cost Indicator ('Milieu Kosten Indicator – MKI'), is used which could serve as inspiration for the Belgian Government.

Theme 5, customer demand: Participants assumed that there is a lack of willingness to pay extra for sustainable products from end-users. In this perspective, the government is one of the main end-users and can play a crucial rule in demanding a higher level of sustainability in its constructions.

Theme 6, acceptance of NORM contained by-products: For the study participants, their familiarity with hazardous materials plays an important role in the degree to which they allow NORM-contained by-products in cement. Previous experience with addressing NORM issues or related challenges (e.g. experience with residues containing heavy metals) plays a role in the acceptance. Provided that sufficient experience is available a more open attitude toward acceptance can be present. In this context, strict standards, guaranteeing the safety of end-users, play a pivotal role in facilitating the acceptance of NORM contained by-products in cement. Although, for some participants the perceived risk related to recycling of NORM containing by-products was higher and this resulted in more hesitation towards the acceptance of this type of materials. Another factor that played an important role in the acceptance of the materials by cement and concrete producers are potential associated worker risk related to the production of the binders. In addition, even if the materials are safe during their use, concerns were phrased by the study participants on the end of life and future reuse/recycling. A major challenge in using NORM-contained by-products is situated in the risk communication. To communicate the complexity of NORM related issues to the general public / end users which might lead to panic or overreactions.

Conclusion

A detailed overview of the chemical, radiological, mineralogical characterisation of PG and its performance in AAMs is given. From a systematic stakeholder perception study, we extract as key hypothesis that regulatory certainty is a crucial requirement that can contribute to the acceptance of NORM and in particular PG based cementitious binders. Based on the interview analysis, we also hypothesise that a need is present for an overarching approach that targets involved stakeholders via among others existing regulatory barriers lifting, sustainable innovative materials certification,

implementation of higher rate green taxis and better incorporating sustainability in public procurements.

Acknowledgements

Support for this work was provided by the King Baudouin foundation [project 2020-E2141050-E001] and the Horizon 2020 Euratom research and training programme under grant [agreement No 900009, RadoNORM project].

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