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Circular economy meeting with sustainable solutions for mining waste: turning residues into glasses and glass-ceramics

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Abstract

Mining is an extraction process by definition. It is thus responsible for natural resource depletion which represents an environmental impact. In order to slow down depletion, mining companies must introduce circularity in their processes. Circularity is a sustainable action, and it would allow one to rethink their position in the supply chain and chemical product design. In turn, the chemical nature of residues from mining may indicate the possibility to upcycle this material and turn it into glasses and glass-ceramics for floors and coverings in construction for example. This communication intends to share a well successful conversion of a zinc-processing residue into monoliths of glass and glass-ceramic aiming Proof of Concept (PoC).

Introduction

It is estimated that since scale economy and the development of a mass production industrial system, world population consumes one and a half planet per year (WEETMAN, 2019), which concerns specialists on Earth's resilience limits – i.e., biocapacity (STEFFEN *et al.*, 2015). This is justified by the expectation that world population will reach around 8.5 billion inhabitants, from which 60% will be in urban areas (UNITED NATIONS, 2020). In turn, concepts, and methods from circular economy (STAHEL, 2016; BERGER *et al.*, 2020; ELLEN MACARTHUR FOUNDATION, 2020; SONDEREGGER *et al.,* 2020) offer alternatives to waste generation and environmental impacts derived from natural resources depletion. For example, circularity is built in the concept of mass and energy flow retention by means of introducing loops in processes (UNEP, 2020). In this regard, waste evaluation as raw-material for glass and glass-ceramic production (FONSECA, 1990; FONSECA *et al.*, 2004; RAWLINGS *et al.*, 2006; ZANOTTO, 2010; FONSECA, 2019) represents an alternative to undesirable disposal of processing effluents and to contentment with conventional solutions, such as tailings dam. In Brazil, dam failure occurred in Mariana and Brumadinho, both from the state of Minas Gerais, and lead to the review of the Law 12334/2010 (BRASIL, 2010), concerning the National Dam Safety Policy (BRASIL, 2020). The objective of this communication is to share the results from the case study of converting a zinc-processing residue into glass and glass-ceramic aiming Proof of Concept (PoC) for chemical product design.

Material and Methods

Zinc-processing residue

The residue from a zinc-processing unit is a solid inorganic waste and it was supplied by the company NEXA RESOURCES in order to evaluate scientifical and technological potential for producing glasses and glass-ceramics. It was previously characterized (Chemical Analyses, XRD and heating microscopy) and treated, including drying at environmental conditions, crushing, classification, homogenization and quartering.

Methods

The methods developed in this work are common to the ones from glass and ceramic industries. An amount of 60 g from the residue was melted to the temperature of 1400°C which is above its flow point and two routes were defined: the *frit* and *bulk* routes. The *frit* route was quenching the melted residue to water at environmental temperature. The next step in this route was classification and comminution to define the size distribution and to gather sufficient amount of sample for characterization – i.e., XRD, DTA and heating microscopy. Then, the glass powder was cold formed, annealed at 675°C and crystallized at 850°C to produce a glass-ceramic monolith which was afterward finally polished. The *bulk* route was hot forming the melted residue and annealing it at 675°C to produce a glass monolith. Crystallization followed at the temperature of 850°C and a glass-ceramic monolith was produced. Melting, annealing and crystallization were processed at electric furnaces and cold forming was processed in a mould by pressing – i.e., 19.6 MPa for 30 s.

Characterization

Chemical analyses consisted in Atomic Absorption, Inductively Coupled Plasma (ICP), Potentiometry, Gravimetric and Volumetric analyses. Partial composition was kept confidential by NEXA RESOURCES. Heating microscopy was conducted from environmental temperature to 800°C at a heating rate equals to 12°C/min and from 800°C to 1500°C at a heating rate equals to 10°C/min (DIN 51730/ISSO 540). In turn, thermal analysis was conducted in an inert atmosphere and by a heating rate equals to 10°C/min. Finally, XRD followed the Powder Diffraction Method in the upcoming conditions: X-Rays 40 kV and 20 mA, scanning from 5° to 90° 2θ and step of 0.02°.

Results and Discussion

Results from the residue analyses

Results from the characterization of the residue lead one to conclude on the potential of its glass-forming ability once chemical analyses indicated the presence of glass-forming elements in its composition as well as the sum of $SiO_{2\ \%p/p}$ (34.7% $_{p/p}$) and $Al_2O_{3\%p/p}$ (0.2% $_{p/p}$) contents to be lower than 85% which consists an upper bound to economic feasibility (STRNAD, 1986). Also, the XRD revealed *anglesite*, *sphalerite*, *gipsite* and *jarosite* as the major crystal phases in the mineral constitution of the residue. The presence of those minerals allowed one to identify an opportunity to introduce circularity to the process of producing glasses and glass-ceramics from this residue. Furthermore, those minerals contain sulphur in their chemical structure and their decomposition releases SO_x which is a representation of toxic gases. However, sulphur can be retained as sulphuric acid which is a chemical commodity imported from Brazil, for example. Then, industrial symbiosis may be considered to reduce costs and expand revenue. Finally, heating microscopy revealed flow and softening points equal to 1239°C and 1140°C, respectively. The melting point is consistent with the glass industry practice.

Glass-transition and crystallization temperatures

Samples for characterization were obtained from the *frit*. No crystal phase was identified in the XRD analysis which is consistent with the purpose of the quenching technique – i.e., producing non-crystalline solid. Thermal analysis indicated two thermal behaviours: a deflection of DTA curve between 650°C and 680°C – i.e., indicating glass-transition temperature equals to 650°C – and an exothermic peak around 850°C – i.e., crystallization temperature. In turn, heating microscopy revealed flow ánd softening points equal to 1270°C and 1160°C, respectively. After crystallization, the major crystal phase revealed by XRD was *hedenbergite*. Figure 1 exhibits glass and glass-ceramic monoliths produced by the *bulk* route and the *frit* and glass-ceramic monolith produced by the *frit* route.

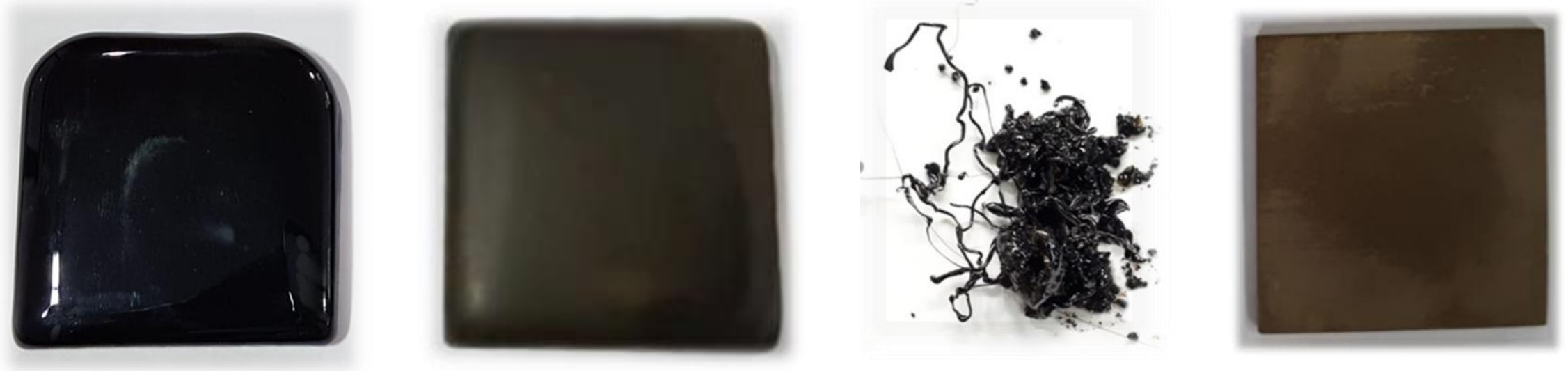

Figure 1. Glass and glass-ceramic monoliths produced from mining residue. At the left, glass and glass-ceramic monoliths produced from *bulk* route. At the right, *frit* and glass-ceramic produced from *frit* route.

Conclusions

Glass and glass-ceramic monoliths were well successful produced from usual techniques from glass and ceramic industries and potentially useful for floors and coatings in construction. Mining residue was considered as raw-material for the production of these materials and no need for additives was verified. Besides, an opportunity to retain a pollutant by-product gas in the technosphere was identified. Thus, circularity could be introduced to the process of glass and glass-ceramic production from mining residue through industrial symbiosis, inter-industry open loop and circular design based on circular economy.

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References

BERGER, M.; SONDEREGGER, T.; ALVARENGA, R.; BACH, V.; CIMPRICH, A.; DEWULF, J.; FRISCHKNECHT, R.; GUINEÉ, J.; HELBIG, C.; HUPPERTZ, T.; JOLLIET, O.; MOTOSHITA, M.; NORTHEY, S.; PEÑA, C.A.; RUGANI, B.; SAHNOUNE, A.; SCHRIJVERS, D.; SCHULZE, R.; SONNEMANN, G.; VALERO, A.; WEIDEMA, B. P.; YOUNG, S. B. *Mineral resources in life cycle impact assessment – part II: recommendations on application-dependent use of existing methods and on future method development needs*. The International Journal of Life Cycle Assessment v. 25 p. 798-813. 2020.

BRASIL. Lei N° 12334, de 20 de setembro de 2010. Available in: http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2010/lei/l12334.htm

BRASIL. Lei N° 14066, de 30 de setembro de 2020. Available in: https://www.in.gov.br/en/web/dou/-/lei-n-14.066-de-30-de-setembro-de-2020-280529982

ELLEN MACARTHUR FOUNDATION; GRANTA DESIGN; LIFE. *Circularity Indicators: An Approach to Measuring Circularity*. *Methodology*. Disponível em: <http://www.ellenmacarthurfoundation.org/circularity-indicators/>. Acesso em: 13 fev. 2020.

FONSECA, M.V.A. Reciclagem de Rejeitos Sólidos: Desenvolvimento, em escala de laboratório, de Materiais Vítreos a partir do Xisto Retortado de São Mateus do Sul, PR. Orientador: Pérsio de Souza Santos. São Paulo : USP/Escola Politécnica, 1990, 224p. Tese. (Doutorado em Engenharia – Engenharia Química).

FONSECA, M. V. A.; OLIVEIRA, C. H.; NEUMANN, R.; ALCOVER NETO, A. *Sintering and Crystallization Studies of Industrial Waste Glasses*. Proceedings of the 8th International Congress on Applied Mineralogy, International Congress on Applied Mineralogy; 2004b; Águas de Lindóia, Brasil, p. 285-288.

FONSECA, M. V. A.; MOTTA, C. F. C.; RODRIGUES, L. M.; SIQUEIRA, M. F.; MONTEIRO, J. K. L. S.; GOMES, R. A. M. *Uso de Rejeitos de Mineração como Matéria-Prima para Produção de Materiais Vitro-cerâmicos*. In: XXVIII Encontro Nacional de Tratamento de Minérios e Metalurgia Extrativa. Belo Horizonte, 2019.

RAWLINGS, R. D.; WU, J. P.; BOCCACCINI, A. R. *Glass-ceramics: Their production from wastes – A Review*. J Mater Sci 41 p.733-761. 2006.

SONDEREGGER, T.; BERGER, M.; ALVARENGA, R.; BACH, V.; CIMPRICH, A.; DEWULF, J.; FRISCHKNECHT, R.; GUINEÉ, J.; HELBIG, C.; HUPPERTZ, T.; JOLLIET, O.; MOTOSHITA, M.; NORTHEY, S.; RUGANI, B.; SCHRIJVERS, D.; SCHULZE, R.; SONNEMANN, G.; VALERO, A.; WEIDEMA, B. P.; YOUNG, S. B. *Mineral resources in life cycle impact assessment – part I: a critical review of existing methods*. The International Journal of Life Cycle Assessment v. 25 p. 784-797. 2020.

STAHEL, W.R. *Comment: Circular Economy*. Nature. Vol 531. p.p. 435-438. 2016.

STEFFEN, W.; RICHARDSON, K; ROCKSTRÖM, J; CORNELL, S. E.; FETZER, I.; BENNETT, E. M. BIGGS, R.; CARPENTER, S. R.; DE VRIES, W.; DE WIT, C. A.; FOLKE, C.; GERTEN, D.; HEINKE, J.; MACE, G. M.; PERSSON, L. M.; RAMANATHAN, V.; REYES, B.; SÖRLIN, S. *Planetary boundaries: Guiding human development on a changing planet*. Science 347, Edição 6223. 2015.

STRNAD, Z. Glass-Ceramic Materials: Liquid Phase Separation, Nucleation and Crystallization in Glasses. Glass Science and Technology 8. Elsevier. 1986.

UNEP. United Nations Environment Programme. Available in: https://www.unep.org/circularity. 2020.

UNITED NATIONS. Department of Economic and Social Affairs, Population Division. *World Population Prospects 2019: Highlights* (ST/ESA/SER.A/423). 2019.

WEETMAN, C. *A circular economy handbook for business and spply chains: repair, remake, redesign, rethink*. Autêntica Business©, 2019.

ZANOTTO, E. D. *A bright future for glass-ceramics*. American Ceramic Society Bulletin vol. 89, N°8 p. 18-27. 2010.