Upcycling of waste glasses: engineering of chemical compositions and chemical attack

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Abstract

Vitrification is one of the safest technologies for the stabilization of inorganic waste. Being capital and energy intensive, its application to industrial waste (such as mining residues, ashes, slags, i.e. beyond radioactive waste) is controversial. A key to sustainability is represented by the definition of useful products, from the reuse of the obtained glasses, to generate extra revenues. Typical products consist of dense and porous glass-ceramics, from viscous flow sintering of fine glass powders with concurrent crystallization. Dense glass-ceramics, developed from waste-derived feedstock and fired at temperature not exceeding 1000 ◦C, may offer superior strength and hardness, compared to stoneware ceramics, developed from natural raw materials and fired above 1100 ◦C. Porous glass-ceramics combine, compared to polymer-based thermal insulators, superior strength and durability: a long service life obviously maximizes the energy saving. In the perspective of valorisation of waste-derived glasses, new opportunities rely on alkali activation, i.e. on the suspension of waste-derived glass powders in aqueous solution of alkali hydroxides, resulting first in surface dissolution and then in progressive hardening, due to condensation reactions occurring to dissolution products (at 40-75 ◦C). Before complete gelation, suspensions may be conveniently foamed, just by intensive mechanical stirring (also with the help of surfactants). Highly porous glass-ceramics are achieved by sinter-crystallization of hardened foamed suspensions, with a clear advantage on conventional methodology, involving gas release by additives operating during sintering: beyond avoiding extra costs from additives (such as SiC), the new method prevents risks of inhomogeneity, resulting from the contrast between gas expansion (requiring low viscosity) and crystallization (increasing the viscosity of softened glass). Alkali activation is not just a processing tool: according to the engineering of the chemical composition (namely Na2O/SiO2, CaO/SiO2, Al2O3/SiO2 ratios) of glass, dissolution and condensation reactions may be tuned in order to provide highly durable (Ca- and Na-) alumino-silicate hydrated gels, defining new construction materials (possibly replacing conventional cements) without any thermal treatment. The dual role of alkali activation may be exploited even beyond glasses from the melting of industrial waste (waste glasses as 'waste-derived' glasses), i.e. to glasses representing by themselves forms of inorganic waste (more properly 'waste glasses', remaining unemployed), such as glasses from the dismantling of pharmaceutical containers, opal glass, residues from the manufacturing of glass fibres, or contaminated soda-lime cullet. Sintering of alkali-activated foamed suspensions may be applied at particularly low temperatures (e.g. 700 ◦C, for soda-lime glass), with evident energy savings and avoided risks of volatilization of some components (e.g. fluorine, for opal glass). More importantly, stable

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gels may be achieved by activation at low molarity (NaOH or KOH solution nota above 3 M), for the definition of products usable not only in constructions, but also for absorption and catalytic degradation of organic waste (such as organic dyes). Alkali activated glasses may be finally used for the additive manufacturing of various structural and functional components, according to different technologies (such as direct ink writing and inkjet printing).

Keywords: Waste vitrification, Waste glasses, Alkali activation, Gelation, Additive manufacturing