How to remove toxic metal-rich road dust from urban environments? A new eco-friendly remediation approach

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Palabras Clave: Polvo de carretera, metales tóxicos, remediación, sostenibilidad. **Key Words:** Road dust, toxic metals, remediation, sustainability.

INTRODUCTION

Ambient particulate matter pollution, which can be accumulated on urban roads, is one of the global modern society challenges (WHO, 2016). This road dust is constituted by different fractions of geogenic and anthropogenic particles, which commonly act as a potentially toxic elements (PTEs) temporary storage. In low-income countries, long-term exposure to traffic-generated dust was estimated to cause every year 1.5 to 2 million premature deaths, mostly children and women. In high- and middle-income countries, there is also an increasing awareness and concern of the potential adverse impacts of dust on health (Navarro-Ciurana et al., 2023). The current methods applied to reduce road dust are based on: i) their recovery by sweep cleaning and subsequent accumulation in wastelands, increasing the local pollution in these areas, and ii) their street elimination with water cleaning, which produce an increase of dissolved metals on urban runoff and residual waters. Consequently, remediation tools to efficiently eliminate the road dust's PTEs from the environment are urgently needed. Vitrification of polluted soils has been applied as an in- and ex-situ remediation procedure, where they are used as raw material in the glass manufacture (Roca et al., 2021). However, this promising technique has not yet been applied to road dust. We present here for the first time the application of the vitrification technique of heavy metal-polluted roadside dust as an eco-friendly remediation solution. This study is based on road dust from Barcelona Province (Badalona city) to illustrate their potential as a new raw material for glass production. This could be an eco-friendly solution to attenuating the environmental pollution problem and prejudicial health impacts in a sustainable circular economy context, as well as to obtain an economic benefit.

MATERIALS AND METHODS

The chemical composition of the collected road dust was determined by inductively coupled plasma optical emission spectrometry (ICP-OES) and ICP-mass spectrometry (ICP-MS). Dry fractionated road dust at <125 μm (80 wt.%) was mixed with Na_2CO_3 PANREAC (20 wt. %) to fabricate the glass by means of a melting in an Al crucible at 1450ºC (holding: 2 h). A fraction of the casting was quenched in a Cu plate, and another was annealed at 540ºC. The mineralogical characterization of dust and glass was conducted by X-ray power diffraction (XRD). The glass thermal behavior was characterized by Differential Thermal Analysis (DTA), using Pt-Rh crucibles (80 mL/min air flow, heating 10ºC/min). The manufactured glass was treated at the DTA peak temperatures during 2 h to identify the mineral phases formed by XRD means. The glass rheological properties were determined by: i) the glass-transition temperature (T_g) and the linear expansion coefficient (20-400ºC) from annealed glass using a Lynesis horizontal dilatometer; and ii) the viscosity-temperature (η–T) curves, which have been plotted from fixed viscosity points identified from quenching glass using a hot stage microscopy (HSM; Garcia-Vallès et al., 2013).

RESULTS AND DISCUSSION

The road dust composition shows an adequate SiO_2 (53.40 wt.%), Al_2O_3 (7.68 wt.%), CaO (10.88 wt.%) and K_2O (2.16 wt.%) content, high Fe_2O_3 (3.24 wt.%) and low Na_2O (1.09 wt.%) concentration. Consequently, 20% of Na_2CO_3 was added to road dust for vitrification. The main metal pollutants are Sb, Cu, Zn, Cr, Sn, Pb, Ni and W.

The produced glass does not present XRD peaks, indicating their amorphous structure and the absence of crystalline phases. The DTA curve (Fig. 1a) shows a slight change in slope at 574 °C related to T_g, followed by two single exothermic peaks: one at 691ºC, which corresponds to nepheline crystallization temperature, and another at 879ºC corresponding to wollastonite and gehlenite crystallization. Melting of the crystallized phases during the thermal treatment occurred at 1050ºC and 1091ºC. The dilatometric softening point (T_d) is 586ºC and the temperature transition (T_g) is 524ºC (Fig. 1b), showing an expansion coefficient of $14.12 \cdot 10^{-6}$ $^{\circ}C^{-1}$, which is higher than in a soda-lime glass ($8 \cdot 10^{-6}$–$9 \cdot 10^{-6}$ $^{\circ}C^{-1}$) and similar to glasses produced from polluted soils (Roca et al., 2021). The glass η–T curves, elaborated with the fixed dilatometric T_g to a viscosity of $10^{12.3}$ Pa·s indicate a conformation (10^8–10^3 Pa·s) and workability (10^5–10^2 Pa·s) ranges comprised between 771 and 1199ºC and from 1003 to 1313ºC, respectively. According to the moldability temperature working range between 10^6 and 10^3 Pa·s, glasses can be classified as short (ΔT: < 400ºC) or long (ΔT: > 400ºC; Fernández-Navarro et al., 2003): the fabricated glass resulted then as a short glass (ΔT: 311°C; Fig. 1c), enabling it for future automatic manufacturing.

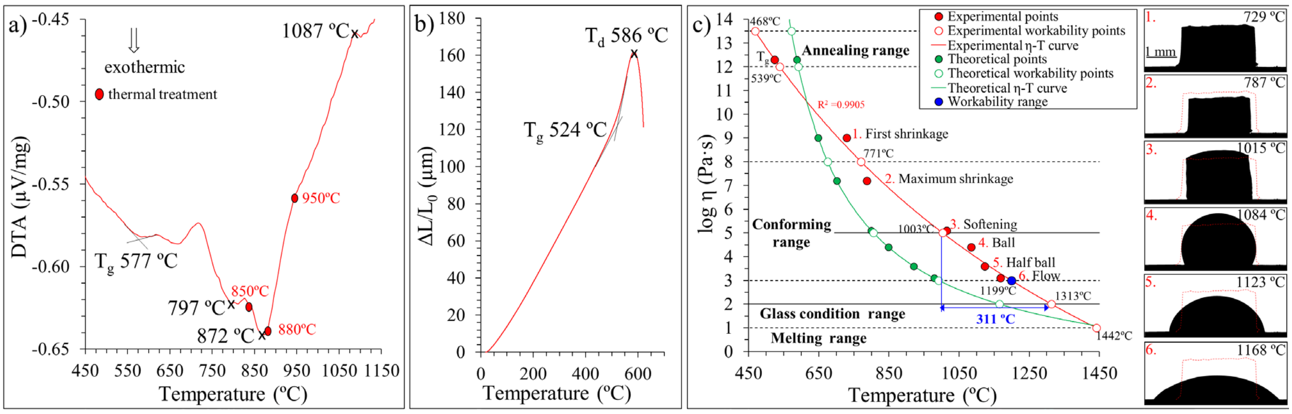

Fig 1. *a) Glass DTA curve. b) Thermal dilatometric curve used to determine Tg and Td. c) Glass viscosity–T curves, workability intervals and hot-stage photomicrographs (1 to 6) of the glass with the temperatures fixed viscosity points DIN-51730 (1976).*

CONCLUSIONS

The results presented here indicate that vitrification is an appropriate technique for efficient remediation of polluted road dusts by adding a minor amount of sodium. Although more work is need, the vitrification technique will constitute an eco-friendly remediation solution of the urban dust by their use as raw materials in automatic glass manufacturing, promoting also a sustainable circular economy by the commercialization of recycled road dusts as glasses or enamels.

ACKNOWLEDGEMENTS

This research was funded by: POC2022_2 to D. Navarro and M. Corbella granted by the Universitat Autònoma de Barcelona; and the Consolidated Research Groups GEOXiS (No. SGR-0026) and MAGH (No. 2022-SGR-00308) of the Catalan Government of Spain.

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