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Recycling trachyte waste from the quarry to the brick industry: Effects on physical and mechanical properties, and durability of new bricks

Chiara Coletti [a,*], Lara Maritan [a], Giuseppe Cultrone [b], Maria Chiara Dalconi [a], Anno Hein [c], Eduardo Molina [d,e], Claudio Mazzoli [a]

[a] *Department of Geosciences, University of Padova, Via G. Gradenigo 6, 35131 Padova, Italy*
[b] *Department of Mineralogy and Petrology, University of Granada, Avda. Fuentenueva s/n, 18002 Granada, Spain*
[c] *Institute of Nanoscience and Nanotechnology, N.C.S.R. 'Demokritos', Aghia Paraskevi, 15310 Athens, Greece*
[d] *Centro de Excelencia en Geotermia de los Andes (CEGA, FONDAP-CONICYT), Universidad de Chile, Plaza Ercilla 803, Santiago, Chile*
[e] *Centro de Investigación en Nanotecnología y Materiales Avanzados, CIEN-UC, Pontificia Universidad Católica de Chile, Avenida Vicuña Mackenna 4860, Santiago, Chile*

HIGHLIGHTS

- Trachyte waste represents an excellent alternative temper for brick production.
- Trachyte used as temper improves the physical and mechanical properties of bricks.
- Recycling waste may reduce requirements for raw materials currently exploited.

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ABSTRACT

This work examined the possibility of recycling trachyte waste as temper for preparing new types of bricks, thus reducing disposal costs and requirements for increasingly vulnerable raw materials, ultimately reducing production costs. The influence of the waste addition was studied by determining the petrographic and physical characteristics of fired bricks, in order to assess their aesthetic and mechanical features. Alkali feldspars in trachyte turned out act as fluxing agents, favoring partial melting of the matrix. Textural and mineralogical analyses revealed a considerable increase in the number of connections among minerals, extensive re-crystallization of the matrix, and an overall increase in compactness, not only with increasing firing temperatures but also increasing trachyte contents. The physical and mechanical properties of all samples were comparable with those of traditional bricks, showing that the addition of trachyte confers sufficient technical features already at 900 °C, allowing further reduction of production costs by lowering firing temperatures.

1. Introduction

For millennia, clay bricks have been used as building materials, thanks to their excellent properties. From both environmental and economic perspectives, bricks are still valuable, inert and efficient construction materials. In the last few decades, extensive research has been conducted on industrial brick production, solving several environmental problems and improving sustainable development [1–8].

Improving sustainable production levels implies reduced exploitation of primary geo-resources, together with better waste management and disposal by re-assessment of residual materials as secondary resources to be used in producing new materials. Awareness of the enormous amount of waste generated by industrial processes in an age of rising environmental concerns has stimulated increasing interest in the re-use of waste and addressed research to the development of environment-friendly construction materials.

In the last few decades, many studies have examined such re-use of waste as a potential alternative to some of the primary resources used in producing bricks. Recycling organic compounds such as paper [9–12], cotton [11], tea-leaves [13], rice [14], tobacco [3], sawdust [15], biomass [16–18] and biodiesel [19] have been proposed and tested to increase brick porosity. The effect of some inorganic waste additives have been also studied, e.g. material derived from natural stone processing such as perlite [20], marble [15,21–23], pozzolana [24], fly ash [25,26], or other secondary

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* Corresponding author.
E-mail address: chiara.coletti@unipd.it (C. Coletti).

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industrial materials such as sewage sludge [27–30], ceramic sludge [31] and leach residues [32]. Nevertheless, transfer of knowledge and technology is still very limited. Introducing waste materials into brick production may represent a sustainable solution to the problem of disposing of large volumes of substances resulting from various industrial activities, which now constitute environmental hazards worldwide [33,34]. The need to dispose of these materials and the increasing demand to develop sustainable alternatives to traditional building materials has attracted both industrial and academic attention to the production of new environment-friendly bricks [35,36] optimizing the quality of end-products and reducing their cost [37].

From this perspective, the choice of considering trachyte waste in designing a new type of brick derives from the following considerations: i) trachyte is a natural stone which does not release polluting substances or contaminants, either during firing or in use, for better environmental and social acceptance; ii) feldspars, which constitute the main mineralogical phases in trachyte, may act as fluxing agents during firing, thus improving the technical properties of bricks [38–40]; iii) recycling waste from stone processing may reduce disposal issues on one hand, and the costs of raw materials and supply on the other. This latter aspect also meets the requirements of two companies working the same industrial district (in north-east Italy), one quarrying and processing trachyte from the Euganean Hills, and the other in producing traditional bricks. In addition, re-using trachyte may represent a return to an ancient custom that of saving time and energy by taking advantage of all the possible resources of the territory, including waste materials, as attested by the ceramics produced in the course of thousands of years, from the Late Bronze Age to the Iron Age and then Roman times in north-east Italy [41–44].

The present work relies on a carefully designed multi-analytical approach to investigate the physical–mechanical properties and durability of nine brick types, obtained by adding trachyte waste to the same clayey material in order to explore new green solutions and encourage environmental-friendly brick production, sustainable use of natural resources and energy-saving processes, and promoting excellence in innovation.

2. Experimental procedure

2.1. Preparation of samples

The mix designs consist of clayey material from the alluvial plain of the Po (north Italy), known as '*Rosso Casaglia Forte*', tempered with sand-sized fragments of trachyte, mostly in the range 0.160–0.400 mm (Fig. 1a), obtained by grinding residual waste from quarrying and ornamental stone cutting.

Three types of experimental mixes were obtained by adding 5, 10 and 15 wt% of trachyte to the clayey material by means of a soft-mud process used for hand-molding. Plasticity was attained by adding water and manually working the mix, which was then placed in a 5 × 12 × 20 cm wooden mold, coated with sand to prevent the clay from sticking to the inner sides of the mold, and to favor water drainage during pressing and release. For each of the three experimental mixes fifteen samples (5 × 12 × 20 cm) were mold, five to be fired at 900 °C, five at 1000 °C and five at 1100 °C. Bricks were fired in an electric oven (Table 1) with 15 h heating time, 5 h soaking time, and 15 h cooling time (Fig. 1b).

2.2. Analytical techniques

The chemical composition of the clayey material was determined by X-ray fluorescence (XRF) on an S4 Pioneer (Bruker AXS) spectrometer, with an estimated detection limit of 0.01 wt% for major elements; ZAF method was systematically employed [45], and the NCSDC 74301 (GSMS-1) standard [46] was used. X-ray powder diffraction (XRPD) was applied to identify the mineral phases of raw materials and fired products. Diffraction data were acquired on a PANalytical X'Pert PRO diffractometer, operating in Bragg-Brentano reflection geometry with CoKα radiation, 40 kV of voltage and 40 mA of filament current, equipped with an X'Celerator detector. Qualitative analysis of diffraction data was carried out with X'Pert HighScore Plus® software (PANalytical) and the PDF-2 database. Quantitative estimation of phase fractions (QPA) was obtained by applying the Rietveld method as implemented in Topas v4.1 software [47]. A known amount (10 wt%) of the internal standard zincite (J.T. Baker) was mixed with powdered samples of the fired bricks, in order to estimate the amorphous content according to the combined Rietveld-RIR method.

The petrographic and textural characteristics of thin sections were examined under a polarized-light optical microscope (Olympus DX-50), equipped with a Nikon D7000 digital microphotography system.

Texture and reaction microstructures were examined by Scanning Electron Microscopy (SEM) with a CamScan MX-2500

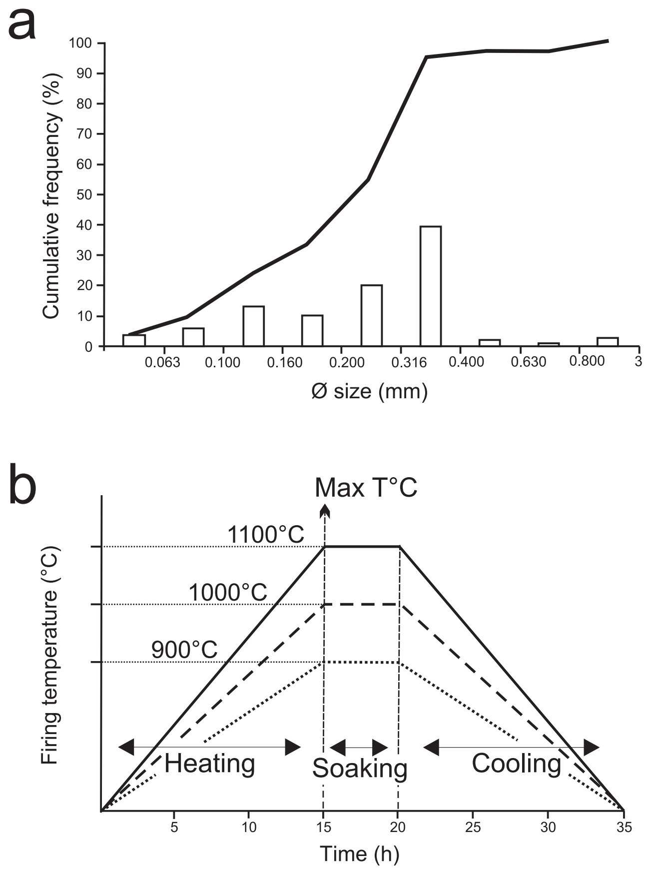

Fig. 1. a) Cumulative frequency curves of trachyte grain-size distribution; b) firing temperature vs. time.

Table 1
Trachyte waste content and firing temperature of bricks, including labels.

Raw materials		Firing temperatures (°C)		
Clay	Trachyte waste (wt%)	900	1000	1100
Rosso Casaglia Forte	5	B5.09	B5.10	B5.11
	10	B10.09	B10.10	B10.11
	15	B15.09	B10.10	B15.11