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Studying the feasibility of a selection of Southern European ceramic clays for the production of lightweight aggregates

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Abstract

Nine clays traditionally used in the ceramic brick and tile sector in Southern Europe were evaluated for the production of lightweight aggregates: four from Spain, three from Portugal and two from Italy. The clays' suitability was thoroughly examined according to their capacity for pelletizing, their tendency to burst during heating, the firing temperature and their technological properties. A greater proportion of phyllosilicates over nonplastic components is directly related to the bursting of the pellets during preheating. Increased sand contents and $SiO_2/(\sum Flux = K_2O + Na_2O + CaO + MgO + FeO + Fe_2O_3)$ ratios are connected to higher firing temperatures, the opposite occurring with the MgO percentage. Those clays with a higher iron content (highlighting in this study the two Italian clays and the Spanish red one) would be more optimal for the development of an expanded structure. The findings of this work show that Southern Europe holds clay deposits with enormous potential in the production of lightweight aggregates. In particular, the red clay from the Zocca deposit (Italy) is remarkable for its excellent characteristics for the production of expanded lightweight aggregates (bloating index of 24.4% and loose bulk density of 0.47 g/cm^3). These raw materials could have a new market line due to the multiple applications of lightweight aggregate in construction (lightweight concrete), horticulture as well as in civil and environmental engineering.

Introduction

Aggregate is the second most consumed raw material by man only behind water. Its sector is the main supplier of raw materials for the construction of infrastructures and buildings, as well as for industry and environmental protection, which confers it a clearly strategic character [1]. Although the consumption of artificial lightweight aggregates is significantly lower than that of natural aggregates (<1% in the former compared to 99% in the latter, according to 2017 data from the Spanish sector [2], the low density, high porosity, inert character and reasonable mechanical strength of lightweight aggregate, make its applications extend in a multitude of fields [3]: lightweight concrete (decreasing not only its density, but also favoring internal curing), masonry, pavements, geotechnical engineering, water treatments, green roofs or horticulture, among others. Although the lightweight aggregate sector has remained “stagnant” for a few decades, the growing environmental concern and the significant advantages of lightweight aggregate should boost its production in the future, so its market is expected to grow mainly as the demand for lightweight and thermally insulating concrete increases [4].

According to Ayati et al. [4], natural clays and clayey residues are currently the most suitable raw materials for the production of lightweight aggregates due to their high availability close to urban areas and their particular characteristics. Some examples of the use of clays and/or clay-rich wastes for the production of lightweight aggregates are shown in the studies by Loutou and Hajjaji [5], Anan and Abd El-Wahed [6] and Kanari et al. [7].

The plasticity of the clay would play an important role in pelletizing, while an adequate chemical composition and particle size can lead the pellet to expand under certain firing conditions (usually flash-firing by thermal shock), giving rise to the highly porous and low-density internal structure of the lightweight aggregate [8], [9]. Sintering is the most critical step of the process. As Riley [8] indicated more than sixty years ago, lightweight aggregate is formed thanks to the simultaneous occurrence of two conditions:

i) the development of a rather viscous phase at a temperature close to the melting point (but never reaching it, since only some of the phases become fused)

ii) the release of gas (usually CO_2, CO, H_2O, H_2, O_2, SO_2 or Cl_2) from the decomposition of some organic and mineral species (such as calcite, dolomite, phyllosilicates, metallic sulfides, chlorides or ferrous minerals, among others).

iii) Only if these two conditions are met concurrently, the gas is entrapped within the viscous matrix and pore formation is thereby encouraged. This process is usually accompanied by a significant volume increase (bloating or expansion) in comparison with the size of the original pellet.

Given the enormous potential of lightweight aggregate in various sectors, the clays used so far in traditional ceramics (such as bricks and tiles) could be of interest for its production. Such a study has been addressed in this research with nine ceramic clays from Southern European countries (Spain, Portugal and Italy). The examination of their viability has been approached in a novel way, not only focusing on the technological properties of the sintered material, but also on the most relevant aspects of its production, such as the pelletizing capacity, the tendency to burst during firing and the associated energy consumption. With regard to this last aspect, high sintering temperatures would entail higher energy, economic and environmental costs, so their reduction would be a priority. In reference to bursting, unlike the slow firing carried out on traditional ceramics such as bricks and tiles, the production of lightweight aggregates typically involves rapid heating by thermal shock. As a result, the pellets can burst if firing is not adequately controlled, mainly by applying a preheating that prevent this phenomenon. Obviously, the preheating stage should be as short as possible to avoid massive loss of gases, without which the porous structure of the lightweight aggregate could not be developed [10]. For its part, pelletizing is highly conditioned by the plasticity of the material, since *plasticity* ("the ability of the material to be molded to any shape" [11]) is a key property in the processing of ceramic materials. Plasticity establishes the technical parameters required to transform a particulate ceramic body into a component with the desired shape by pressure application [12]. Thus, broadly speaking, nonplastic or low-plastic samples (e.g., silts and sandy soils) would not be suitable for pelletizing because they crumble very easily when handled. On the contrary, plastic samples (clays and clayey materials) present a range of water content inside the plasticity index, PI, in which the plastic behavior is conspicuous. However, the capability to withstand plastic deformations varies along the PI range, so that not all the water contents are equally valid for this aim due to changes in toughness and stickiness. Thus, if the sample is too dry (very close to or below the plastic limit, PL), the extrusion and pelletizing processes are constrained because the sample becomes too stiff (slightly above PL) or even nonplastic (below PL), making extrusion and pelletizing difficult. By contrast, very high water contents (especially close to or above the liquid limit, LL) could imply that the sample adheres to the extruder tube, that more flaws appear in the extruded thread, that greater shrinkage occurs and/or that the green pellets lose their shape [13], [14], [15], [16], [17]. According to Sembenelli [13], the ideal material is one that can be molded with the minimum water content and offers the minimum shrinkage, presenting relatively low LL, PL and PI values. This material should be workable and should dry out with limited deformation and low calorie consumption, which is more common in kaolin and kaolinite clays than in fat clays, like bentonites [13]. The use of the optimal moisture content, W_{OP}, deduced from the study of Moreno-Maroto and Alonso-Azcárate [18], seems to be a good solution in obtaining the most suitable plasticity in the extrusion and pelletizing of lightweight aggregates, as was already demonstrated in previous works [19], [20].

Obviously, the characteristics of sintered aggregates must take precedence over the production process itself, which could be readjusted if necessary. In view of all this, an innovative raw material assessment protocol has been developed with the main objective of evaluating the operational (pelletizing, bursting tendency and energy consumption) and technological feasibility (focused mainly on bloating, density and mechanical strength) of nine Southern European industrial clays for the production of lightweight aggregates: four from Jaén (Spain), three from Pombal (Portugal) and two from Modena (Italy). Obtaining lightweight aggregates from the Southern European clays in this study could add value to these raw materials. Thus, their production could lead to an economic impulse in these regions, affecting not only the ceramic sector, but also others in which the lightweight aggregate has a strong application, such as construction materials, agriculture or civil and environmental engineering.

Section snippets

Sampling and initial preparation of raw materials

The mining exploitations of the four Spanish clays studied are located in the province of Jaén (Andalusia, Southern Spain). Specifically, the red clay (SR) was supplied by the company Arcillas y Transportes, S.L. from its mine belonging to the district of Carboneros. The Spanish white (SW), yellow (SY) and black (SB) clays came from Bailén, provided by the company Comercial Cerámicas de Bailén, S.A. The Portuguese clays were supplied by Corbário Minerais Industriais, S.A. Two of them are…

Suitability of clays for pelletizing

The particle size plays an important role in plasticity, since this property is associated with the finest fraction of the material, the so-called clay fraction. According to the results of Table 1 and Fig. 1, the nine clays studied present a very fine grain size distribution, with an average particle diameter and a d_{50} of around 20 µm and 10 µm, respectively. IR is the finest sample, with only 1.1% sand and an average size of 9.1 µm, while the coarsest one is PR, with a sand percentage of…

Conclusions

An innovative raw material assessment protocol has been developed with the main objective of finding out whether nine clays traditionally used in the ceramic brick and tile sector in Southern Europe (deposits from Spain, Italy and Portugal) can be also suitable for the production of artificial lightweight aggregates. As a novelty, the suitability of the clays was evaluated from both an operational (working conditions) and a technological point of view (characteristics of the sintered…

Acknowledgments

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Use of clay in the manufacture of lightweight aggregate

Constr. Build. Mater. (2018)

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2023, Ceramics International

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Study of physical and mechanical behavior of artificial lightweight aggregate made of Pakistani clays

2023, Construction and Building Materials

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Effect of the addition of organic wastes (cork powder, nut shell, coffee grounds and paper sludge) in clays to obtain expanded lightweight aggregates

2023, Boletin de la Sociedad Espanola de Ceramica y Vidrio

> *Citation Excerpt :*
> …Since these types of ceramic clays and wastes, or other similar ones, can be found in basically all countries, the results obtained from this research could be potentially “extrapolated” to other raw materials of similar characteristics. According to the experimental protocols followed by the authors in previous publications [4,17,32–34], a complete characterization of the raw materials was carried out, determining the following parameters: particle size distribution; plasticity (liquid limit, LL; plastic limit, PL; plasticity index, PI; classification); optimum moisture content for extrusion and pelletizing (WOP); mineralogy; carbon content (total, TC; organic, OC; and inorganic, IC); chemical composition; loss on ignition (LOI); thermal behavior; and gross and net calorific values for the organic wastes (GCV and NCV, respectively). The specific methods for determining each of these parameters are shown in Table 1.…

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Use of bauxite tailing for the production of fine lightweight aggregates

2022, Journal of Cleaner Production

> *Citation Excerpt :*
> …The composition design of LWA can be based on Riley's (1951) ternary phase diagram, or the $SiO2/\sum$fluxing ratio (Fakhfakh et al., 2007) and the $(SiO2+Al2O3)/\sum$fluxing ratio of raw materials (Chen et al., 2010). Other factors influencing the pore formation of LWA include the type, fineness, and shape of the raw materials (Wei and Ko, 2017; Cougny, 1990), aggregate size (Lee, 2016; Molinari et al., 2020), firing method (Moreno-Maroto et al., 2020a), and aeration rate (Wie et al., 2020). Recently, a study published by Cobo-Ceacero et al. (2022) thought that the pore structure of LWA using organic wastes can be developed using two fundamental methodologies.…

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Recycling of agricultural irrigation canal sludge and mirror factory residue in green brick production

2022, Construction and Building Materials

> *Citation Excerpt :*
> …The dry samples (n = 4) were fired in a laboratory-type electrical furnace (Siemens, Germany) at a rate of 10 °C/min

until obtaining 950 °C and 1050 °C, for a cycle of 26 h to achieve strength. The particle size of raw materials plays a critical role in plasticity [32]. Clay particle size percentage, which is a good indicator of plasticity and workability [33], for the MFR and AIC sludge was 78.25 % and 30.58 %, respectively (Table 2)....

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