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Research article

Development of lightweight aggregates from stone cutting sludge, plastic wastes and sepiolite rejections for agricultural and environmental purposes

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ABSTRACT

Three different wastes have been assessed for lightweight aggregate (LWA) manufacturing: granite and marble sludge (COR), sepiolite rejections (SEP) and polyethylene-hexene thermoplastics (P). A preliminary study of the physical and chemical properties of the raw materials was carried out to design proper batches. It was mixed 10% SEP with 90% COR to confer plasticity, and in turn, 0, 2.5, 5 and 10% (w/w) of P was added to check its suitability as a bloating agent. The mixtures were milled, kneaded with water, extruded, shaped into pellets, oven-dried and finally fired at 1100, 1125 and 1150 °C for 4, 8 and 16 min. The main technological properties of the aggregates related to bloating, density, porosity, loss on ignition, water absorption and compressive strength were measured. Scanning Electron Microscopy was used to study the microstructure of some LWAs. 23 out of 29 types of aggregate were lightweight, although neither bloating effect was observed, nor the typical cellular structure comprised of shell and core with relatively large pores was obtained, but a structure consisting of micropores and microchannels. The increase of temperature and time of firing involved a greater sintering, which in turn was translated into higher shrinkage, density and compressive strength values, but less porosity and water absorption. The addition of P did not involve any improvement, indeed it caused a significant decrease in compressive strength. The LWA sintered without P at the minimum time (4 min) and temperature of firing (1100 °C) was selected to assess its water suction capability. The results pointed out that this LWA could be suitable in hydroponics and/or water filtration systems, even better than the commercial LWA Arlita G3. A new and most environment-friendly perspective in LWA industry arises from here, promoting LWA production at relative low temperatures (prior to significant sintering occurs) and using non-plastic silty wastes instead of clays as major components.

1. Introduction

Nowadays, environmental policies are being established by most of the developed countries, so that wastes are intended to be valorized as new raw materials (Torres et al., 2009). Recycling processes have long been researched in the ceramic industry, which can contribute to diversify the offer of raw materials, reducing in turn, the costs of production (Menezes et al., 2005). Moreover, the high temperatures that are generally used during sintering (>1000 °C) enable the immobilization of hazardous components (González-Corrochano et al., 2012; Segadães et al., 2005). Lightweight aggregates (LWAs) are granular materials with a loose bulk density (ρ_B) less than 1.20 g/cm^3 or a particle density (ρ_A) not exceeding 2.00 g/cm^3 (UNE-EN-13055-1, 2003), whose characteristics make them really interesting to be used in concrete

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Abbreviations

BI	Bloating Index (%)
COR	Granite and marble waste
COS	90% COR + 10% SEP
C_R	Rate of capillary suction (cm/h)
H	Void percentage (%)
IC	Inorganic carbon (%)
LL:	Liquid limit
LOI	Loss on ignition (%)
LWA	Lightweight aggregate
OC	Organic carbon (%)
P	Thermoplastic waste
P_C	Closed porosity (%)
PI	Plasticity index
PL:	Plastic limit
P_O	Open porosity (%)
P_T	Total porosity (%)
ρ_A	Particle density (g/cm^3)
ρ_B	Loose bulk density (g/cm^3)
ρ_{matrix}	Relative density of aggregate matrix (g/cm^3)
ρ_S	Skeleton density (g/cm^3)
S	Compressive strength (N/mm^2)
SEP	Sepiolite rejection
SSA	Specific surface area (m^2/g)
TC	Total carbon (%)
T_F	Melting temperature (°C)
T_{F0}	Incipient melting temperature (°C)
T_S	Sintering temperature (°C)
T_{S0}	Incipient sintering temperature (°C)
WA_{24}	Water absorption after 24 h immersion (%)
W_{OP}	Optimal moisture content (%)
z	Capillary rise (cm)
z_{24^*}	Capillary rise perceived after 24 h by measuring water content (cm)
z_{24}	Capillary rise perceived visually after 24 h (cm)

production, civil engineering, geotechnics or agriculture, among others. Even though LWAs origin may be natural, they can also be artificially manufactured via high temperature sintering, involving a thermal shock in which a viscous mineral matrix able to trap the evolved gases is formed (Ehlers, 1958; Riley, 1951). Thus, LWAs usually present a cellular structure whose features are of great interest in several industrial sectors. An excellent background reappraisal of wastes used so far for LWAs manufacturing is described in Dondi et al. (2016): sewage sludge, fly and bottom ash, ornamental stones powders, waste clay materials, steel dust, washing aggregate sludge, among many others are gathered. Some of the most recent studies about the use of wastes as raw materials to sinter LWAs are those of Liu et al. (2017) with sewage sludge and river sediments, Li et al. (2016) using sewage sludge and saline clays, Chen et al. (2016) improving the sintering conditions by adding paper sludge in the mixture, as well as the study of Franus et al. (2016) about the microstructural changes suffered when used oil is added to manufacture LWAs.

In the case of the ornamental rock sector, the unsuitable deposition of granite and marble wastes in the form of sludge can cause necrotic conditions in rivers and lagoons, inflicting damages to living organisms (Acchar et al., 2006; Segadães et al., 2005; Torres et al., 2004). Most of the researches about the use of granite-marble sludge as a component in ceramics are concerned with the manufacture of usual housing materials, such as bricks or tiles, whose features may be even better than the commercial ones (Acchar et al., 2006; Dhanapandian and Gnanavel, 2009; Dhanapandian et al., 2009; Menezes et al., 2005; Segadães et al., 2005; Torres et al., 2004, 2009; Vieira et al., 2004). Few studies about the use of this kind of waste in LWA production can be found in the literature: De' Gennaro et al. (2009) manufactured LWAs from granite cutting sludge and porcelain stoneware tile polishing sludge. Bloating effect was mainly detected in those samples with larger amounts of porcelain powder, rather than in the granite samples, due to the presence of significant contents of SiC (expanding agent). In a recent work of Soltan et al. (2016), LWAs manufacturing using granite sludge and clay was assessed. The results pointed out that only those pellets with more than 20% of clay gave rise to really porous and lightweight aggregates, so the granite powder would not be able to bring forth LWAs by itself, unless an expansive component is included.

The potential use of thermoplastic polymers as bloating agents for LWA manufacturing is reported in the patents developed by Kirschner (1976) and Malloy et al. (2003), but its use for pore formation in ceramics is more related to other sectors, such as biomedicine (Fu et al., 2008; Vitale-Brovarone et al., 2008). Likewise, some studies explain the use of sepiolite in sintering of porous cordierite ceramics (Zhou et al., 2011) or sanitary bodies (Li et al., 2015), but there are not references about its use in LWAs production.

The present research is focused on the development of LWAs using ordinary granite-marble cutting sludge as major component, unmarketable sepiolite rejections as binder additive and thermoplastic wastes as porous generator, so that these materials may be managed as technological raw materials in ceramic processes instead of valueless residues. Despite the fact that the studies related to LWAs are mainly intended to produce lightweight concrete in which the aggregates have preferably a limited pore interconnection, the target of this research is to obtain LWAs with high hydraulic conductivity to be used in agriculture hydroponics (Sloan et al., 2011) and water filtration systems (Meng et al., 2015; Subriyer, 2013). Therefore, a significant open porosity without the typical shell-core structure will be sought, which opens the possibility of saving energy and costs by using lower sintering temperatures and shorter dwell times than in ordinary processes.

2. Materials and methods

The methodological framework followed in this study was based on that described by González-Corrochano et al. (2009a,b) who manufactured LWAs from washing aggregate sludge, fly ash, used motor oil, sewage sludge and natural clays.

2.1. Sampling and initial preparation of raw materials

The sepiolite rejection (SEP) was supplied by the clay-mining company Tolsa, S.A. (Vallecas, Spain) and preserved in polyethylene bags when collected. This clay is mainly commercialized as granular absorbent in pet litters. The sepiolite processing comprises: 1) clay extraction and initial crushing, 2) drying, 3) final crushing, 4) sieving and grain size selection, 5) packaging. Therefore, the sample SEP came from the material that is not commercially interesting due to its small grain size (in this case SEP aggregate size was around <1 mm). These rejections are staked in