Lightweight aggregates made exclusively from waste: an alternative raw material contributing to Sustainable Construction

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Pollution is one of the main problems that significantly affect our planet's natural resources and climate change. One of the most important anthropogenic sources of environmental pollution are cities, and the buildings that compose them. In this sense, the United Nations Environment Programme states that 'buildings are a very important part of environmental degradation', since on the one hand they consume large amounts of natural resources in their construction, and on the other hand they are responsible for 40% of greenhouse gas emissions and the generation of 35% of the EU's total waste (European Commission). In the scenario described above, there is a clear need to start using environmentally friendly techniques and materials. An evolution of the current building system towards sustainable construction is necessary. One material that has a major impact on the construction sector is aggregate, being one of the most widely used materials in this sector. Furthermore, a study published by Zhong et al (2022) indicates that the global demand for sand will increase by 45% by 2060. This increase will lead to a shortage of this material, which will encourage the use of alternative materials such as gravel, slag, aggregates, demolition waste and crushed concrete mixed with cement. This expected increase in demand for aggregates will have a negative impact on the natural reserves of this material, so alternative options such as artificial aggregates obtained from waste materials are of great interest.

This work focuses on obtaining artificial lightweight aggregates made exclusively from waste, using a protocol to establish the formulations and the subsequent analysis of the characterization results of the LWAs obtained through the Mixing Experiments - Design of Experiments (ME-DOE) methodology using the statistical software R (Moreno-Maroto et al., 2023). The materials obtained can be used to manufacture lightweight concrete or green roofs, or in other activities such as gardening and horticulture.

Six different waste materials were used. Three of mineral origin: aggregate washing sludge (AWS), granite cutting sludge (GCS) and slate cutting sludge (SCS), and three organic additives: cork dust (CD) generated in the manufacturing process of bottle stoppers, coffee grounds (CG) and olive pulp (OP), waste generated in the production of virgin olive oil. All wastes have been characterized by determining the particle size distribution by laser diffraction, the chemical composition by X-Ray Fluorescence and the thermal behaviour by simultaneous Differential Thermal Analysis-Thermogravimetric Analysis (DTA-TG) in air atmosphere. Additionally, and only for inorganic samples, dilatometric tests have been carried out and the mineralogy of the sample has been studied by X-ray diffraction both in polycrystalline powder and in oriented aggregates.

ME-DOE uses regression models to determine the effect of the components of a mixture on the properties of the LWA. Complex models such as quadratic, special cubic or cubic models are used for this purpose. Depending on the model used, it is necessary to consider a minimum number of tests to estimate the model coefficients. Fig. 2 presents the proposed ME-DOE that works with 3 final components for each set of experiments:

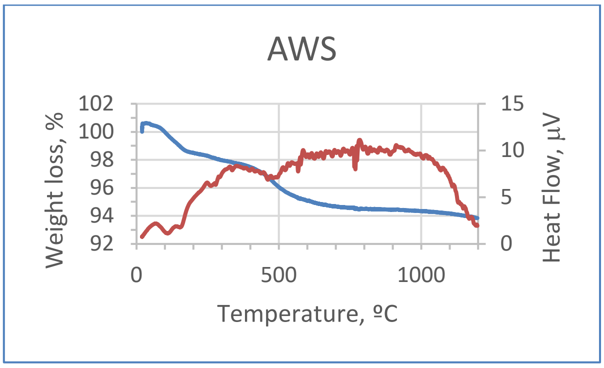

Fig. 1. DTA-TG graphs in air atmosphere for the AWS

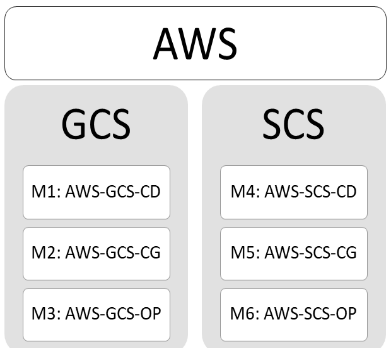

Fig. 2 Design of experiments

The limits established for each of the components of the mixtures have been based on preliminary tests for GCS and SCS (70 and 80 % by weight, respectively). For the organic additive, the upper limit has been set at 3 % by weight in accordance with published work indicating that higher percentages of organic matter can restrict the expansion process in LWA (Cobo-Ceacero et al., 2023). The third component, AWS, has been added up to 100 %. Using the Xvert function of the R mixexp package, the 13 formulations necessary to allow the estimation of the best fitting model for each LWA property have been defined (Table 1). Mixtures M1 and M2 contain only inorganic residues, so that the effect that the addition of the organic residue has on the expansion capacity can be established.

Table 1. Composition of the mixtures studied

	AWS-GCS-OA*			**AWS-CCS-OA***		
	Components, %			Components, %		
Mix	**AWS**	**GCS**	**OA***	**AWS**	**SCS**	**OA***
M1	100.00	0.00	0.00	100.00	0.00	0.00
M2	30.00	70.00	0.00	20.00	80.00	0.00
M3	97.00	0.00	3.00	97.00	0.00	3.00
M4	27.00	70.00	3.00	17.00	80.00	3.00
M5	63.50	35.00	1.50	58.50	40.00	1.50
M6	65.00	35.00	0.00	60.00	40.00	0.00
M7	98.50	0.00	1.50	98.50	0.00	1.50
M8	81.75	17.50	0.75	79.25	20.00	0.75
M9	28.50	70.00	1.50	18.50	80.00	1.50
M10	46.75	52.50	0.75	39.25	60.00	0.75
M11	62.00	35.00	3.00	57.00	40.00	3.00
M12	80.25	17.50	2.25	77.75	20.00	2.25
M13	45.25	52.50	2.25	37.75	60.00	2.25

* OA: represents any of the three organic additives CD, CG or OP

To characterize the manufactured LWAs, a number of properties have been determined. The LOI of the preheating and firing stages (LOI_{preh} and LOI_{firing}, respectively) was determined on 25 samples as the percentage change in weight before and after heating in the rotary kiln. The bloating index (BI) calculated as the percentage change in size experienced by the same samples above. The loose bulk density (ρ_b), apparent density (ρ_a), oven dry density (ρ_{rd}) and 24 h water absorption (WA_{24}) have been determined according to EN-1097-3 and EN-1097-6. Total, open and closed porosity (P_T, P_o and P_C) were determined from the densities ρ_a and ρ_{rd}, assuming a density of the solid phase of the aggregate (ρ_{sol}) of 2.6 g/cm^3 (Akers et al, 2003). The mechanical strength (S) was determined using a Nannetti®FM 96 press. Finally, all those aggregates obtained that have a ρ_b and/or ρ_{rd} lower than 1.2 and 2.0 g/cm3 respectively, will be considered as LWAs according to the EN-13055-1.

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