Construction and Building Materials 98 (2015) 376–387

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

# The manufacture of lightweight aggregates from recycled masonry rubble

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## HIGHLIGHTS

- Heterogeneous and fine-grained masonry rubble as feedstock for the production of lightweight aggregates.
- Results of experiments on the conditions for the manufacturing.
- Results of the experiments on the technical and environmental characterization of the material.
- Concrete production in laboratory and technical scale.
- Outlook on technology, energy consumption and further suitable feed materials.

## ARTICLE INFO

*Article history:*
Received 28 January 2015
Received in revised form 28 April 2015
Accepted 12 July 2015
Available online 28 August 2015

*Keywords:*
Recycling
Masonry rubble
Expansion process
Rotary kiln
Lightweight aggregate
Lightweight concrete
Resource efficiency

## ABSTRACT

At present, heterogeneous and fine-grained masonry rubble can only be recycled at very low level. To overcome this limitation, the material was employed as feedstock for the production of lightweight aggregates in a thermal process similar to that used in the manufacture of expanded clay and expanded slate. To that end, the fundamental suitability of masonry rubble as a raw material was evaluated. Experiments were carried out which indicated that lightweight granules with defined, adjustable properties similar to those of natural-material-based aggregates could be manufactured from masonry rubble. Structural lightweight concretes produced with these secondary aggregates achieved comparable performance to lightweight concretes produced with conventional expanded clay. Lightweight recycled building material aggregates represent a product that hardly requires any primary resources in its manufacture. In principle, the technique also seems to be well suited for high-quality recycling of other mineral waste materials.



## 1. Introduction

At present, the mix of various wall construction materials, mortar, plaster, and further components that make up recycled masonry rubble cannot be adequately utilized. This results from the considerable heterogeneity of the material composition and the large proportion of fines. In Fig. 1 a typical input pile of masonry rubble consisting of clay brick, other masonry blocs and a fine unidentifiable fraction is shown. For this material, there are no suitable recycling options. On recycling facilities the temporarily stored amounts of masonry rubble grow. The dumping fees increase or the acceptance is completely denied.

In the future, strict closed-loop recycling laws and limited landfill capacity will prevent the disposal or application of these materials as fill or in the construction of landfills completely. In this context, a technology for the manufacture of lightweight aggregates from masonry rubble was developed as part of a joint research project. These lightweight construction aggregates are produced from mineral construction waste and can be employed in the manufacture of lightweight mortars and concretes.

To date, lightweight aggregates have been primarily manufactured from natural resources. In areas with a volcanic history, that includes naturally occurring stone such as pumice, tuff, and lava. These materials are quarried and processed for use as lightweight aggregates for the manufacture of mortar and concrete. Other lightweight aggregates are produced synthetically, through a thermal technique – analogous to the natural process – that expands and stabilises the granulate material. Clay and slate that meet

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http://dx.doi.org/10.1016/j.conbuildmat.2015.07.027
0950-0618/

**Fig. 1.** Example for the input pile of masonry rubble at a recycling plant.

the following requirements are natural raw materials for these synthetic lightweight aggregates:

- When heated, the material must achieve a pyroplastic state with a favourable viscosity.
- A quantity of gas sufficient for pore formation must develop within the pyroplastic temperature range.

Industrial by-products are another source of raw materials for the manufacture of lightweight aggregates. Well known examples include coal fly-ash and bottom ash from power plants, which can be directly employed following mechanical processing. Recovered glass can also be used as a feedstock for lightweight aggregates [1–3]. Following the grinding process, it must be run through a shaping and firing process as well. Additional industrial by-products under consideration for the manufacture of synthetic lightweight aggregates, as described in the technical literature, include:

- Coal wash waste and flotation residues from coal processing, as well as with the addition of red mud [4–6].
- Ash from combustion processes [7–10].
- Fine particle waste from pumice processing [11].
- Uncontaminated or contaminated sediments and sludge from rivers, lakes, and water reservoirs, as well as sewage sludge [12–18].

Thus, the raw materials are extremely diverse. They originate from different sectors of the waste industry. So far, building rubble has been missing from this range of materials, despite being quantitatively the dominant type of waste. Whether building construction and demolition wastes (CDW) can be used to manufacture lightweight aggregates, and thereby enable a closed cycle for fine-grained and heterogeneous materials, is the topic of the research presented in this paper.

## 2. Characteristics of masonry rubble

The quantity of masonry accumulated since 1950 in existing building stock in Germany is illustrated in Fig. 2 [19]. As of 2010, it had reached more than 2000 million tons. The actual quantity may be higher than this value, as the quantity of masonry already existing in the building stock in 1950 is not included in this estimate. The quantity of masonry rubble produced in the demolition and rehabilitation of buildings is in the order of magnitude of 20 million tons. Considering that 15 to 20 million tons of wall construction materials are produced annually, this is a notable potential source of raw materials.

In contrast to concrete rubble and unmixed clay brick rubble, masonry rubble consists of multiple components. As well as brick, other construction materials present can include calcium-silicate brick, aerated autoclaved concrete, precast concrete, or natural stone. Additional components can include lime mortar, lime cement mortar, cement mortar, interior and exterior plasters, insulation, tiles, and façade panels. Recycled aggregates manufactured from this material through comminution and screening can vary greatly in their composition. This has been confirmed by the results of sorting analyses of processed masonry rubble (Fig. 3). The brick and other ceramic material content vary between a minimum and a maximum of 24 and 92 mass% respectively, with a mean value of 50 mass%. Concrete and mortar are the second most dominant material group. The mean is 46 mass% with a range between 8 and 70 mass%.

Within a batch of material there may be a variety of building materials with greatly differing properties. This diversity of materials is reflected in the width of the frequency distribution of the particle density (Fig. 4). Even when materials with a particle density less than 1760 $kg/m^3$ are omitted, the range of the densities is 750 $kg/m^3$.

To date, the consideration of chemical composition as a characteristic of masonry rubble is rarely made. The exceptions are the works by [20,21] indicating the composition of pure bricks and other ceramic products. However, for the recovery as raw materials the composition of masonry rubble is particularly relevant. In order to make an initial assessment, the oxide composition of the unmixed primary components of masonry in the ternary system $SiO_2$–$Al_2O_3$–flux ($CaO + MgO + Fe_2O_3 + Na_2O + K_2O$) is recorded (Fig. 5). This system is used to assess raw materials for ceramic building materials, including those for the manufacture of expanded clay according to [22,23].

Mineral-bound building materials as aerated autoclaved concrete, calcium silica brick or concrete lie virtually along one line in an unmixed state. Their $Al_2O_3$ content has a mean value of 4 mass%. Pure, ceramic-bound building materials set themselves apart from mineral-bound materials through their distinctly higher $Al_2O_3$ content. In contrast, systematic differences in the $Al_2O_3$ content of mixed masonry rubble composed of brick, other coarse ceramics, concrete, and/or other building materials are not discernable.