

LIGHTWEIGHT AGGREGATE FROM RECYCLED MASONRY RUBBLE ACHIEVED IN MICROWAVE FIELD

Lucian Paunescu¹, Marius Florin Dragoescu², Sorin Mircea Axinte^{3,4} and Ana Casandra Sebe⁵

¹Junkoeko SRL Slobozia, Romania, lucianpaunescu16@gmail.com

²Daily Sourcing&Research SRL Bucharest, Romania, mar_dmf@yahoo.com

³Daily Sourcing&Research SRL Bucharest, Romania, sorinaxinte@yahoo.com

⁴Department of Applied Chemistry and Materials Science, University POLITEHNICA of Bucharest, Romania,
sorinaxinte@yahoo.com

⁵CosfelActual SRL Bucharest, Romania, casandrasebe@yahoo.com

ABSTRACT: The work refers to an innovative recycling solution of wastes from demolition and rehabilitation of buildings to produce more cost-effective lightweight aggregates. The adopted method is based on the use of microwave energy as a nonconventional source, replacing conventional energy sources and expanding the powder mixture of raw material with silicon carbide as a foaming agent. The final product has a porous structure and a high compressive strength (over 6 MPa), being suitable for use as a lightweight aggregate for concrete manufacture.

KEYWORDS: masonry rubble, lightweight aggregate, microwave, nonconventional, energy, compressive strength.

1. INTRODUCTION

Lightweight aggregates, used in the manufacturing process of mortars and concretes, can be produced from natural resources (volcanic rocks) or synthetically through thermal processes using natural wastes as clay and slate or industrial by-products as coal ash, sewage sludge etc. In principle, to produce lightweight aggregates it is necessary that, by heating at high temperature, the raw material reaches a pyroplastic state, with a suitable viscosity, to facilitate the formation of a porous structure generated by the oxidation or decomposition of a foaming agent [1].

The masonry rubble belongs to this category of waste from the demolition and rehabilitation of buildings, representing quantitatively the dominant type. What characterizes the masonry rubble is the heterogeneity of the material components. Excepting the concrete rubble and unmixed clay brick rubble, the building wastes can include calcium-silicate brick, aerated autoclaved concrete, precast concrete and additional components as cement mortar, lime mortar, insulation, plasters, tiles and facade panels, whose chemical compositions vary greatly [1].

This demolition and construction waste is an important source of material. It reached maximum values during the post-World War II reconstruction in several countries, especially European (Germany, Great Britain, etc.). At present, the annual rate of masonry rubble production is very high, especially

in Great Britain (70 million tonnes [2]) and Germany (50-60 million tonnes [3]).

The literature presents relatively few information on experiments performed worldwide to manufacture lightweight aggregate from masonry rubble. One of the published work [1] refers to tests and experimental results, the product in the form of pellets of 2 – 4 mm and 4 – 8 mm, respectively, being investigated to identify the physical, mechanical and morphological characteristics. Using different weight proportions of waste components (concrete and natural aggregates, clay brick, other mineral components and impurities) resulted raw material mixtures varying between 1.95 – 2.42 g/cm³, their oxide composition containing mainly SiO₂ (between 67.7 – 76.7 wt.%), Al₂O₃ (8.6 – 12.0 wt.%) and CaO (8.2 – 11.4 wt.%) and low proportions of Fe₂O₃, MgO, K₂O, Na₂O and SO₃. The raw material processing included crushing and screening, grinding (in a ball mill), shaping (in a high shear mixer), firing and stabilization of the pellets (in a laboratory rotary kiln). The optimal firing temperature for the waste foaming with silicon carbide was 1180 °C. The lowest density of the aggregate (1 g/cm³) was obtained at 1160 °C (for the fraction 2 – 4 mm) and 1180 °C (for the fraction 4 – 8 mm). The influence of the SiC dosage on the expansion process of the powder material was analyzed at 1180 °C. Experimentally, it was found that the density can decrease below 0.8 g/cm³ for a SiC dosage of 1% and even below 0.7 g/cm³ for the

SiC dosage of 3%. The compressive strength of the lightweight aggregate obtained by firing at 1160 °C was 4 MPa (for the fraction 2 – 4 mm) and 5 MPa (for the fraction 4 – 8 mm), the values being close to those of expanded clay. The water absorption by immersion of the sample in water for 24 hours indicated a range of values between 8,0 – 15,5%, being significantly lower than that of the expanded clay (14.0 – 25.5%), currently used as a lightweight aggregate for the manufacture of concrete.

The raw material used in the paper [3] was masonry rubble containing mainly clay brick, mortar and plaster as well as other materials, such as lightweight concrete, usual concrete, sand lime brick and aerated concrete. The rubble mixture was crushed and ground in a ball mill at particle size below 100 µm. The powder obtained was mixed with silicon carbide as foaming agent and water in a high shear mixer, which allowed mixing and granulation at the same time. The raw granules were expanded and stabilized in a rotary kiln supplied with fossil fuel. A dosage of 3% silicon carbide and a firing temperature of about 1185 °C led to the maximum expansion effect. The comparison of the lightweight aggregate made from masonry rubble with conventional aggregates of expanded clay did not lead to significant differences.

As noted above, the production of lightweight agglomerate from masonry rubble was based exclusively on the conventional method of heating the raw material in rotary kilns with consumption of pollutant fossil fuel.

Unlike the solutions adopted by the techniques described previously, the experiments conducted by the research team at the Romanian consortium were based on the use of microwave energy for the unconventional heat treatment of the demolition waste and foaming agent (silicon carbide). Further, the peculiarities of this economical and clean method and its experimental results are presented.

2. METHODS AND MATERIALS

2.1 Methods

The method adopted for the production of lightweight aggregate from masonry rubble differs significantly from the methods presented in the literature. The most important difference is the use of microwave energy as an energy source for the thermal treatment of waste from demolition, by comparison with the conventional heating method.

Although the advantages of microwave heating (fast, clean and economical) are well known since the Second World War, a decade ago, this type of

heating was used only in the household for food preparation, rubber vulcanisation and the manufacture of composites polymer-wood. Recent research has shown that the applicability field of the nonconventional heating (with microwaves) can be extended to many types of materials: organics, ceramics, polymers, metals, glass etc. [4].

The microwave radiation is the term associated with any electromagnetic radiation in the frequency range between 300 MHz and 300 GHz. The usual frequency of the microwave ovens, including both domestic and industrial ovens, is 2.45 GHz. The microwave susceptibility is not a feature of all materials, but only of those called dielectrics. They have very few free carriers. By applying an external electric field, very few electrical charges move through the matrix of the material. On the other hand, the molecules or atoms of the dielectric have a dipole motion. This represents two equal and opposite electrical charges, separated by a finite distance. In the presence of an external electric field, the dipoles can be temporarily induced. The distortion of the electron cloud around nonpolar molecules or atoms generates friction inside the dielectric and the energy is dissipated in the form of heat. The interaction of dielectrics with electromagnetic radiation (microwave radiation) leads to energy absorption [5]. The dielectric materials absorb the electromagnetic energy in their entire volume and convert it into heat. Because the material itself is a heat generator, the heating process takes place volumetrically and is very fast [6], radically different from the conventional methods where the heat is transferred by conductivity, radiation and convection. Another important advantage of the microwave heating is the selective heating, which allows that only the material subjected to this process to be heated, not the massive components of the furnace (walls, vault, hearth) as in the case of the conventional heating [5]. Theoretically, due to the content of microwave transparent materials (silica, alumina) of the masonry rubble, the heating since the ambient temperature should be done with difficulty due to the low electrical conductivity, whose value increases only with the temperature increasing [7 - 9]. Practically, due to the presence of some contaminants (mainly Fe₂O₃) in the raw material composition, as well as silicon carbide as a foaming agent, with microwave susceptibility [8], the heating can be carried out with normal efficiency even at room temperature.

Also, unlike the manufacturing techniques of lightweight aggregate from masonry rubble,

described in the literature, the powder mixture of raw material, addition material and foaming agent is loaded into the oven as a homogeneous mass, previously pressed and not in the form of pellets. The product sintered and foamed at high temperature (over 1150 °C), having a porous structure and high compressive strength, is broken into pieces of suitable size for its use as a concrete aggregate. This method was taken over from the known techniques of industrial manufacture of the glass foam from glass waste [10].

The thermal treatment of the finely ground mixture consisting of masonry rubble, coal ash as addition material, silicon carbide as foaming agent and water as a binder was carried out in a 0.8 kW-domestic microwave oven (Figure 1a) adapted for high temperature operation (up to 1200 °C). The wetted material was pressed into a demountable die and then, it was extracted (Figure 1b) and wrapped with several layers of ceramic fiber mattress to avoid heat loss during the microwave heating. For viewing the surface of the heated material and measuring this temperature with a radiation pyrometer placed above the oven, the upper mattresses were provided with a central hole. The microwave field emitted through the waveguide of the generator, placed on one of the sidewalls of the oven, is absorbed directly by the material, which is microwave susceptible due to, at least, of the presence of silicon carbide in the mixture composition. Thus, the powder material is heated rapidly from the inside outwards, ensuring the temperature required for the foaming process (over 1150 °C), consisting of the oxidation of silicon carbide with releasing carbon dioxide, which remains stuck in the mass of the material after cooling and forms a porous structure.

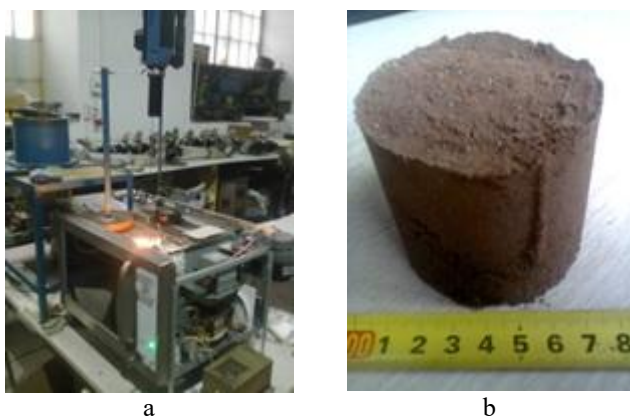


Figure 1. The experimental microwave equipment a – 0.8 kW-microwave oven; b – the pressed material.

2.2 Materials

The raw material used in the manufacturing process of lightweight aggregate is masonry rubble. Its sorted components are: clay brick, usual concrete for building and cement mortar. The weight ratio of the three components was adopted based on the own research, as following: 48/ 40/ 12. The oxide compositions of the demolition wastes are shown in Table 1. The concrete and mortar composition data are the result of the own research.

Table 1. Oxide composition of the raw material

Oxide composition wt. %	Raw material		
	Clay brick [11]	Concrete	Cement mortar
SiO ₂	60.6	68.9	20.0
Al ₂ O ₃	19.2	18.7	3.7
CaO	2.6	1.6	62.8
MgO	2.9	0.5	3.1
Fe ₂ O ₃	8.1	6.5	3.1
Na ₂ O	1.2	0.2	0.1
K ₂ O	3.9	1.5	0.8
TiO ₂	1.3	1.3	-
SO ₃	-	-	3.2
LOI	-	2.7	4.9

The components of the masonry rubble have been crushed and ground together at a grain size below 300 µm in an electrically operated laboratory equipment. Coal ash was used at the granulation with which it was purchased from the Paroseni thermoelectric power station, i.e. below 150 µm. The foaming agent (silicon carbide) had a grain size below 80 µm and it was thus used in the manufacturing process of the lightweight aggregate.

Keeping constant the waste composition, the four variants adopted for the manufacture test of lightweight aggregate (presented in Table 2) have contained different proportions of masonry rubble (85.6 – 90,8 wt.%), coal ash (4.0 – 9.0 wt.%) and silicon carbide (3.5 – 5.5 wt.%), the water addition proportion being maintained at a constant value (18 wt.%).

Table 2. Variants of the experimental test

Waste composition	Weight proportion value, wt. %			
	Variant 1	Variant 2	Variant 3	Variant 4
Masonry rubble	90.8	87.3	85.6	87.5
Coal ash	4.0	7.7	8.9	9.0
Silicon carbide	5.2	5.0	5.5	3.5
Water addition	18.0	18.0	18.0	18.0

3. RESULTS AND DISCUSSION

3.1 Experimental results

The main functional parameters of the sintering/foaming process are shown in Table 3.

Table 3. Functional parameters of the sintering/ foaming process

Parameter	Var. 1	Var. 2	Var. 3	Var. 4
Raw material quantity (dry/ wet) (g)	460/ 543	463/ 546	462/ 545	462/ 545
Heating duration (min)	32	34	33	33
Sintering/ foaming temperature (°C)	1168	1172	1185	1185
Average heating speed (°C/ min)	35.9	33.9	35.3	35.3
Product quantity (g)	446	449	448	447
Specific consumption of electricity (kWh/ kg)	0.96	1.01	0.98	0.98

The physical, mechanical and morphological characteristics of the four experimental samples are shown in Table 4.

Table 4. Physical, mechanical and morphological features of glass foam samples

Characteristic	Var. 1	Var. 2	Var. 3	Var. 4
Density (g/ cm ³)	0.98	0.86	0.75	0.77
Porosity (%)	60.8	65.6	70.0	69.2
Compressive strength (MPa)	7.3	6.7	6.3	6.0
Thermal conductivity (W/ m · K)	0.140	0.131	0.123	0.125
Water absorption (%)	12.9	13.5	14.3	14.6
Pore size (mm)	1 – 4	0.8 – 4	1 – 4	1 – 4.5

Images of the cross sections of the lightweight aggregate samples are shown in Figure 2.

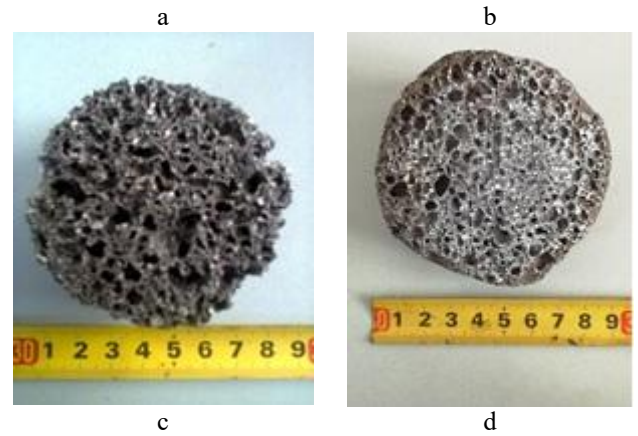


Figure 2. Images of the cross sections of the samples a – sample 1; b – sample 2; c – sample 3; d – sample 4.

3.2 Discussion

The solution of direct heating of the powder mixture containing masonry rubble, silicon carbide and coal ash was adopted after previous indirect heating tests (the material being pressed inside a metal crucible, doubled outward by a cylindrical silicon carbide wall), which led to very low heating speeds, very high process durations and, implicitly, excessive energy consumption. Unlike the heating for foaming glass waste, which is completely inappropriate for the direct microwave heating because it generates major imbalances in the structure of the material, the thermal treatment of construction waste can be applied without structural problems, even if the heating speed exceeds 33 °C/ min.

Because the raw material is an aluminosilicate by its high content of silica and alumina, the process temperature of sintering/ foaming is much higher (1168 – 1185 °C) than the manufacturing temperature of glass foam (generally, below 1000 °C). For this reason, the conventional technological process of lightweight aggregate manufacturing in the rotary kiln is one great energy consumer. The use of the microwave energy is a suitable economical solution in this case.

The coal ash is an addition material currently used to reduce the density of the sintered material. Secondary influences are manifested by increasing the process temperature and reducing the compressive strength of the product. Weight proportions of coal ash of 4 – 9% were used in experiments.

The silicon carbide consumption, used as foaming agent, varied between 3.5 – 5.5 wt.%. A higher proportion than the recommended values (2 – 5%) was used, justified to favour the expansion of the raw material mixture, the silicon carbide being

practically the only microwave susceptible component.

According to the data in Table 3, the specific consumption of electricity achieved during the experimental microwave heating varied between 0.96 – 1.01 kWh/ kg. As mentioned above, the literature does not provide information on energy consumption. In the paper [1] theoretical results on the heat requirement for manufacturing expanded clay and lightweight aggregate from masonry rubble, using conventional energy sources, are presented. Taking into account a thermal yield of the two processes of 0.5, the following specific consumptions were determined: 1.28 kWh/ kg (for the expanded clay) and 1.05 kWh/ kg (for the lightweight aggregate from masonry rubble, with fuel consumption). By comparison, it results that the microwave use allows the energy consumption reduction with 21 – 25% than the expanded clay manufacturing and 3.8 – 8.6% than the aggregate manufacturing from masonry rubble.

4. CONCLUSION

An innovative recycling solution of waste from the demolition and rehabilitation of buildings to produce more cost-effective lightweight aggregates by nonconventional energy consumption was experimentally tested.

An average composition of masonry rubble containing clay brick, concrete and cement mortar was used in the ratio 48/ 40/ 12. Coal ash was the addition material and silicon carbide was selected as the foaming agent.

The heat requirement was ensured by the microwave energy in a 0.8 kW-adapted domestic oven.

From a qualitative point of view, the four variants of lightweight aggregate have physical, mechanical and morphological characteristics similar to the products obtained by conventional heating: density between 0.75 – 0.98 g/ cm³, compressive strength between 6 – 7.3 MPa, thermal conductivity between 0.123 – 0.140 W/ m · K, water absorption between 12.9 – 14.6% and porous structure with pore size between 0.8 – 4.5 mm.

The specific consumption of electricity, calculated at 0.96 – 1.01 kWh/ kg is lower with 21 – 25% than the industrial manufacturing process of expanded clay as a lightweight aggregate and with 3.8 – 8.6% than the experimental process of producing the aggregate

from masonry rubble, the both processes being fuel consumers.

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