Construction and Building Materials 69 (2014) 351–361

Contents lists available at ScienceDirect

Construction and Building Materials

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

Utilization of waste Autoclaved Aerated Concrete as lighting material in the structure of a green roof

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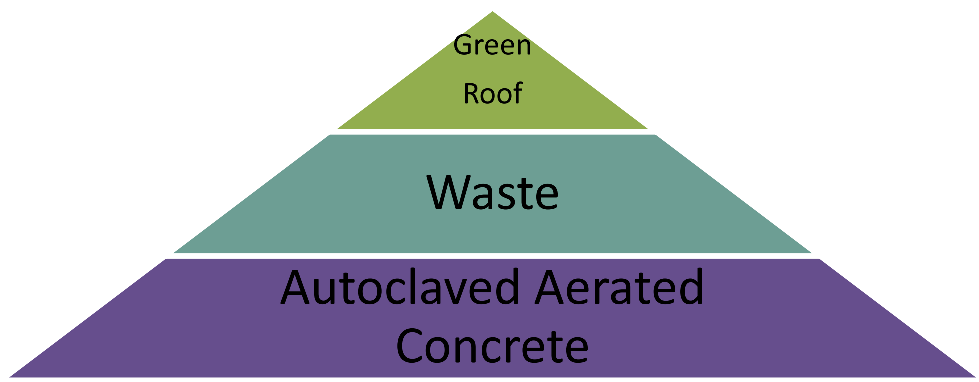
HIGHLIGHTS

- Reuse of waste AAC with natural soil to create a neutral substrate for green roofs.
- AAC–peat mixture respects the UNI 11235 standard.
- AAC–peat mixture is similar to the mixture with natural stones and natural soil.
- Utilization of granular waste AAC reduces the consumption of natural materials.
- AAC cost, obtained by waste materials, is lower than the natural materials one.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 2 April 2014
Received in revised form 27 June 2014
Accepted 23 July 2014
Available online 15 August 2014

Keywords:
Autoclaved Aerated Concrete
Waste management
Green roof
Chemical analysis
Physical analysis

ABSTRACT

Usually, green roofs are made with natural materials, as lapillus or pumice rock, which have the same porous characteristic of the granular AAC. To verify if this substitution was a good hypothesis, we have carried out chemical and physical analysis on a mixture of 70% of soil and natural peat and 30% of granular AAC. We compared all the results with natural green roof characteristics, finding a good connection between these two groups of values. In fact the pH value of the water extract is of 7.23; the organic matter is less than 4.08; the apparent density is 459.2 kg/m^2; the demand for high water retention capacity is completely satisfied by the value of 222.62% of the mass of water absorbed relative to the mass of the dry sample. For this reason, we think that the introduction of granular waste AAC within the structure of a green roof could help to reduce industrial wastes and respects the European ideas of a sustainable future.
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1. Introduction

During the end of XX century, the European Union published new directives on environment to promote a sustainable future with prevention and reduction of the waste production. These new directives pressed all manufacturing sectors to research new way to reuse or recycle their production waste. With this aim we analyzed waste of Autoclaved Aerated Concrete (AAC) produced by an Italian company, to reuse it as lighting material within the structure of green roofs. Similar studies are also in progress in other countries.

1.1. Autoclaved Aerated Concrete

Autoclaved Aerated Concrete – AAC – (detail shown in Fig. 1) is a special kind of concrete, where cement, lime, water, sand and a blowing agent are mixed. It was born in the 20s in Sweden as an

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http://dx.doi.org/10.1016/j.conbuildmat.2014.07.083
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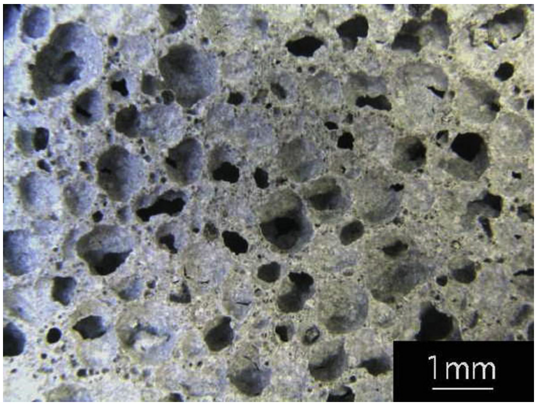

Fig. 1. Detail of a brick made in Autoclaved Aerated Concrete. High porosity characterizes its light structure.

alternative material used for buildings. Subsequently, it spread worldwide as an eco-friendly material and with a negligible environmental impact because it is completely mineral and produced with greatly abundant components.

Porosity is the most interesting feature, whereby this material presents:

- Lightness.
- Ease of transport and installation.
- Ductility.
- Thermal insulation properties.
- Acoustic insulation properties.
- Transpiring properties.

In the AAC production process, during the hardening period, aluminum is added and a gas develops within the structure of the concrete [1]. The pH reaction environment is basic and aluminum, due its amphoteric behavior, melts and oxidizes [2], allowing gaseous hydrogen development:

$$2Al\ (s) + 3Ca(OH)_2 + 6H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 6H_2O + H_2\ (g)$$

Later, porous blocks, still moist, are cooked within autoclaves with quite low temperature, 190 °C, and high-pressure, 12 bar, for about 14 h. In this time, there is a hydrothermal treatment [3] and the formation of tobermorite, whose chemical formula is

$$5CaO \cdot 6SiO_2 \cdot 5H_2O$$

In other words, crystals of calcium silicates, which strongly influence mechanical properties of the final product, are formed. During the initial cooking stage, the silica-based compounds, highly reactive, such as amorphous silica, improve the polymerization of CSH compounds, preceding the direct formation of tobermorite. On the other hand, the presence of aluminum delays the initial formation of the CSH-based compounds reducing the solubility of quartz, but accelerating a direct formation of tobermorite.

Tobermorite formation was studied in 2011 [4], where scientists studied a sample of AAC, using X-ray diffraction, during the hardening period. The results suggested different reaction paths for the formation of tobermorite in an AAC system. In one of them, tobermorite appears when the temperature reaches 190 °C, in other words, when amorphous gel-based CSH begin to decrease. The amount of tobermorite is maximum at the end of the autoclave process. For this reason, it is possible to believe that the most of crystalline tobermorite phase results from the CSH amorphous phase.

Recently, Houston et al. reported that the formation of tobermorite proceeds through three stages [5]: formation of amorphous and non-crystalline CSH, growth of semi-crystals of tobermorite and recrystallization of tobermorite in a solid phase.

During the cooking period, the presence of aluminum influences different aspects of the final product of tobermorite: it has a significant effect on the average length of the chains of silicate and on the stability of the CSH structures; it reduces quartz and lime reactivity, replacing within the structures of the oxides.

1.2. Green roofs

A green roof is a building roof partially or totally covered by a garden. Its main aim is recovering the most important areas within the city that otherwise, would be sterile, transforming the districts appearance just not only in an aesthetical way but also in terms of quality of life [6]. In general, there are two types of green roofs systems: the intensive and extensive green roof [7].

Intensive green roofs are designed with deep substrates, at least 30 cm, and they can withstand a wide range of plants, that require, however, a frequent maintenance. Due the high thickness of the layer, it has a great heat insulating property, but it must be designed with a vapor barrier layer. In the winter season, in fact, water vapor passes from the inside of the heated building to outside, finding the obstacle of an impermeable barrier. In this case, it could condense, moistening the waterproof layer that would lose its main feature. To avoid condensation, this steam must be locked and retained before reaching the insulating layer.

Extensive green roof is composed of draining material and it is thinner (5–12 cm), than the intensive one and it can support the growth of a vegetation resisting to drought and extreme conditions, so requiring less maintenance. Due its lightness (60–250 kg/m^2), this system requires a small, or even non-existent, additional support structure and it has great potential to extend in width.

For each part of the garden structure, detailed studies are carried out, to ensure that dangerous puddles do not form, or to create a good quality cultivation layer and rich in nutrients for plants. Typically, a mixture of different material [8,9] forms it: an organic part of soil and a draining part of natural materials, such as lapillus and pumice stones.

From the reduction of negative environmental effects point of view, green roofs offer many opportunities. The main benefits of a vegetated roof are:

- It cools down the temperature of the air, absorbed by the atmosphere, through plants evapotranspiration, allowing the reduction of the urban "heat island" effect [10].
- It provides passive cooling to the built environment [11] that needs 25% less of conditioned air during in summer and, consequently, provides the reduction of CO_2 emissions. It increases the thermal resistance of the roof, important benefit in winter [12]. The presence of various layers works as filter, reducing the CO_2 crossing.
- It reduces the annual rainwater runoff from roofs, typically 60–70% less [13]. The progressive overbuilding has reduced the drainage capacity of urban areas, which render the sewers obsolete. With new roofs transformed into green roofs, the water absorption increases during raining events, thus preventing the overflow of sewerage systems [14].
- It contributes to local biodiversity, providing a perfect habitat for invertebrates that could live in soil layers and for ground-nesting birds, such as skylarks.
- It improves the life quality of communities developed in high-density areas, contributing to a greener urban environment and reducing the transmission of noise inside the building.

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