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Local Resources Used in the Manufacturing of Sustainable Building Materials

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Abstract

The energy efficiency of the buildings and environment protection are considered to be the most important factors in obtaining a sustainable development of the entire our society. One step to assure these objectives is to exploit the local natural resources in manufacturing of new buildings materials which has low cost, low embodied energy and improved thermal insulation properties. In this respect the paper present five new mortar recipes, using the local zeolitic volcanic tuff, from Macicas quarry (north-west of Cluj - Napoca city) used in different percentage (30%, 50%, 80%), as a substitute of the Portland cement. The mortar samples has been analysed and comparated from mechanical (compressive and flexural strength) and physical (apparent density, real volume, compactness and porosity) point of view showing the differences between them, cost and embodied energy.

Keywords: local resources, embodied energy, volcanic tuff, building materials, sustainability.

1. Introduction

The built environment constitutes one of the main pylons for economic development and social welfare. After the energy crisis in the 70's, people became more and more aware of the fact that issues regarding environment protection cannot be distinguished from economic, social and cultural activity and that they have direct consequences upon human life quality and society development.

The impact of the constructions upon sustainable development must be taken into account to make a built environment that is sustainable and proper for the demands of both today's and future generations which are in a continuous change.

The strategies to adopt the principles of sustainability in constructions should be compatible with the climatic area, the culture and traditions of the people living in a certain area.

Sustainability is not a recently developed concept used in design of dwelling constructions. Elements of sustainability can surely be found in the case of old traditional houses, based on the experience acquired by trial and sometimes inherent errors made along the time when local building materials which have a diminished incorporated technology started to be used [1].

The ecological definition of materials is a process that is both difficult and complex to be achieved.

Their impact upon the environment is hard to appreciate as there are numerous parameters that need to be considered and more than often the available data are improper for an accurate evaluation.

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The objectives of designing buildings on the basis of sustainability consist in providing their energy efficiency while consumption of natural resources (oil, gas) is reduced compared to that used in case of buildings design on traditional principles.

Large local reserves of natural resources and the concern for a sustainable development of the built area have determined some of the researchers in this field to focus upon developing new, ecological and sustainable building materials, having at their basis natural pozzolanic materials like volcanic tuffs.

2. The yse of zeolitic tuffs in mortars as sustainable building materials

2.1 Occurences of Romanian volcanic tuff

Volcanic tuffs have been used since very old times as building rocks and as lightweight aggregates or binders in mortars used to improve old buildings or to erect new masonry structures.

In Romania zeolitic tuffs are important natural resources both of high quality and quantity present in many geological structures (fig. 1), even if are not exploited enough in building material industry.

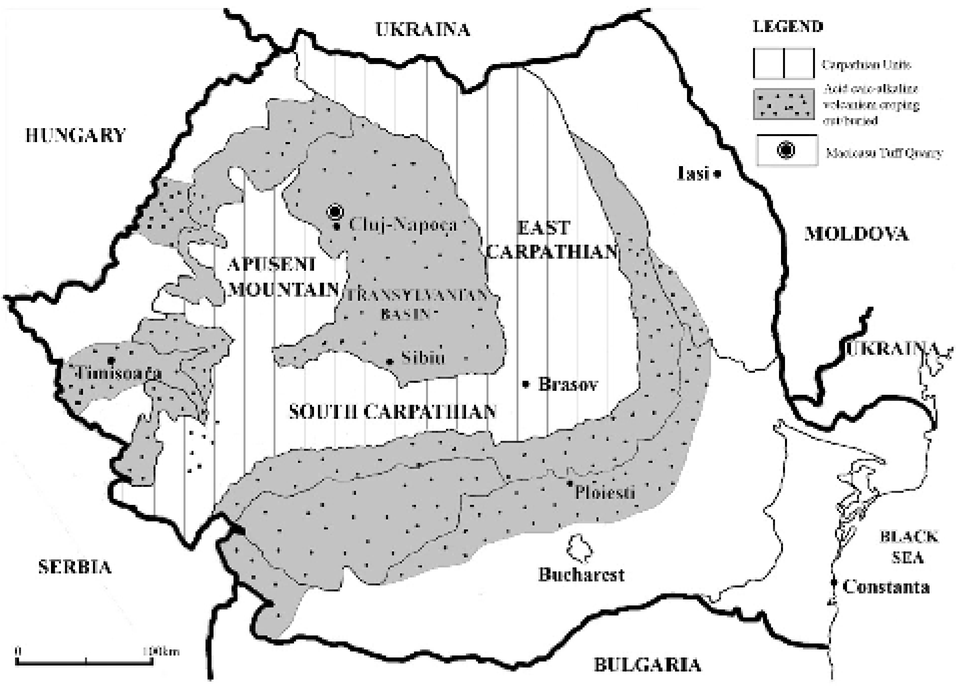

Figure 1. Zeolitic tuffs resources in Romania

One of the most recent exploited occurrences is the volcanic tuff from Macicas quarry, situated in the north-west part of Cluj-Napoca city. From geologically point of view this tuff is a Dacitic one, white-yellowish in colour, with a massive and compact texture and a vitreous-cristaloclastic structure [6].

2.2 Chemical and mineralogical content of volcanic tuffs

A mineralogical analysis of the tuff was performed on powders with the help of a difractometer, with Co-Ka radiation anticathode, λ = 1.790300 Å and 2º θ/min from 10º to 70º (2theta) which it led to the following mineralogical composition: quartz (12.2%), clinoptilolite (40.4%), heulandite (22.1%) and feldspar (25.3%).

Chemical analysis, highlighted the presence of the following oxidic compounds: CaO (5.46%), SiO_2 (63.98 %), Al_2O_3 (14.53), Fe_2O_3 (1.71), MgO (0.23 %), Na_2O (1%), K_2O (0.88%), TiO_2 (0.35%) [3]. The high content in silica, natural alimonosilicates and zeolites give the Macicas tuff the pozzolanic character and hydraulic properties as well.

2.3 Embodied energy of mortars based on zeolitic tuffs

The embodied energy is a significant ecological feature of the building materials considering the energy input required in the entire technological process accompanying the material along its service life cycle, from the production of the raw material to the erection of the building, its service and finally, its demolishing [1].

The largest weight of mortar incorporated energy is represented by the Portland cement, its manufacturing being a process that consumes a lot of energy. About 85% of the gross energy requirement of cement manufacture is in the kiln, where temperatures of about 1450 °C are reached [2], while transforming the tuff in binder is necessary only to grind and cut it without firing.

Lower thermal conductivity of mortars based on zeolitic tuffs (λ = 0.67 – 0.77 W/mK) compared to cement mortar (λ = 0.87 – 0.93 W/mK) and low embodied energy, make zeolitic volcanic tuffs a material suitable for energy efficient buildings.

Building materials made of zeolitic tuffs as admixtures and used as rendering removes heat from environment by desorbing water molecules during the day and releasing them during the night by re-adsorbing water (as a function of temperatures and humidity) assuring in this way the thermal stability of the buildings.

3. Materials and Methods

The materials used to prepare the specimens were Portland cement CEM II/A-S 42,5 R-type, volcanic tuff, sand, water and some additives (plasticiser – recipe R3, air-entraining – recipe R4) according to the recipes presented in Table 1.

Table 1. Mortars recipes

Recipe	Cement 42.5R [Kg/m^3]	Volcanic Tuff [Kg/m^3]	Volcanic Tuff %	A/C	Aggregate [Kg/m^3]
R1	315	135	30	0.57	1350
R2	225	225	50	0.68	1350
R3	225	225	50	0.60	1350
R4	225	225	50	0.60	1350
R5	90	360	80	0.77	1350

During the time, it was proved that natural pozzolanic materials (volcanic ash or tuff, pumice) can be used as cement replacement additives in various proportions. They have the property of setting and hardening at a very slow rate when mixed with water, much accelerated in the presence of cement or fat lime [1].

The method for the production of cork waste mortar and sawdust mortar consists of the following:

- preparation of the volcanic ash or tuff;
- weighing of the materials;
- homogenization of the component materials with the mixer;
- casting of test samples (4x4x16 cm prisms and cubes with a 7 cm side length).

Physico-mechanical determinations were performed after 28 days in the cast test samples, stored according to standards during this period.

4. Results and discussions

Flexural strength for each mortar recipe it has been determined according to SR EN 1015-11/2002 [7, 9] on three prismatic samples having 4x4x16cm dimension. On the halves prism resulted from the flexural determination it was determined the compressive strength at 28 days and mortars brand (table 2).

Table 2. Mechanical properties of mortars samples

Recipe	Flexural strength f_{ti} [N/mm^2]	Compressive strength f_m [N/mm^2]	Mortar class
R1	4.75	17.86	M 15
R2	3.02	11.13	M10
R3	4.80	17.56	M 15
R4	4.03	11.96	M 10
R5	0.70	2.19	M1

The replacement of the Portland cement with volcanic tuff shows a diminution of the mechanical strengths with the increase of the percent of tuff. Compressive strengths at 28 days for all analysed mortar recipes have values between 2.19N/mm^2 (recipe R5) and 17.86 N/mm^2 (recipe R1). Recipes R1 and R3 present higher mechanical strengths, as compared to R5, where 80% volcanic tuff was added and whose compressive strength is only 2.19N/mm^2.

From the results reached, it was also evident that when the plasticiser was used the R3 mortar compressive strength increases by 36.61% as compared to recipe R2. Dissimilar from increased mechanical strengths recorded with the plasticiser used in recipe R3, when the air-entraining additive was used (recipe R4) the compressive strength is only 6.93%.

Apparent density was determined according to SR EN 1015-6 : 2001/A1 : 2007 [8] on prismatic specimens of 4 x 4 x 16 cm while compactness and porosity was determined according to SR EN 998-1, 2 : 2011 (table 3) [10].

Table 3. Physical properties of mortars samples

Recipe	Apparent density [kg/m^3]	Compactness [%]	Porosity [%]
R1	2174	79.32	20.68
R2	2111	75.3	24.7
R3	2135	81.02	18.98
R4	2077	78.32	21.68
R5	2029	71.91	28.09

The table shows that the values of the apparent density ranges between 2029 – 2174 kg/m^3, which includes them in the category of heavy mortars. Using the plasticiser in the mortar mass (recipe R3) has a beneficial effect upon the compressive strength by reducing the water/cement ratio and porosity by 23.15%, as compared to recipes R2, respectively 12.45% if is compared to R4. Using the volcanic tuff in mortars as a Portland cement substitute in various proportions presents the advantage of a low cost and reduced embodied energy, the volcanic tuff cost about only 120 euro/t while the cement costs represent about 200 euro/t. Thus, in the case of new mortars the costs are diminished by 12% (recipe R1), 20% (recipe R2) and 32% (recipe R5).

The embodied energy is reduced with the same percentage of the tuff content in the new mortar recipes (30%, 50% and 80%).

In tuff-based mortars, cement hydration is accompanied by the hydration of zeolites which absorb part of the water in the mortar recipe.

This leads to a smaller amount of portlandite (one of the ***main*** products of cement ***hydrations***) respectively a partial hydration of C_2S. Dipayan Jana (2007) found that the increased strength of mortars based on tuff to sulphate attacks is mainly due to the reduction of the calcium hydroxide amount, produced during hydration phases [5].

The diminishing of the amount of calcium, the high resistance of zeolites in acid solutions, the compact pore structure of mortars (fine pores of small radii) are other elements that confer the mortars made of volcanic tuff a higher resistance to sulphate attacks as compared to mortars made of Portland cement.

Zeolitic tuffs used in mortars specimens as admixtures reduce the risk of expansion and cracking, due to lower heat of hydration. Colella et. all (2001) shows that in case of concrete zeolites have the ability to incorporate the free alkalis and to minimise the reactions between hydroxide ions in the pore water of the concrete [4].

4. Conclusions

It is well known that a building material is sustainable if it withstands to mechanical, physical and chemical damages and its impact upon the environment along its entire service life is as small as possible. In order to increase efficiency, sustained efforts should be made in the industry of manufacturing materials to implement technological reforms able to reduce the detrimental impact upon the environment.

Embodied energy, CO_2 emission and cost of building materials can be reduced through exploitation of local resources (natural -volcanic tuff or artificial pozzolanic materials).

These materials can be used in new mortars or concrete by replacing the binder (Portland cement, lime) or aggregates in different proportions.

One of the most important advantages is related to their manufacturing process.

To extract the tuff from the quarry is similar to extract the limestone (necessary to cement production) from the quarry, but the tuff need to be only grinded, while the limestone must be grinded and burned at high temperature (1450°C) to transform it into cement.

In this respect, using the tuff as a substitute of the Portland cement, the impact upon the environment will be substantially reduced, workability is improved, and impermeability or resistance of mortars due the sulphates attack are increased as well.

The manufacturing industry of new building materials should extend the application of alternative sources of energy (biomass, solar energy) to reduce fossil fuels consumption and emissions of the CO_2 in the atmosphere.

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