Expanded glass spheres applications for low thermal transfer

O Mocanita1, D Chicet2, B Istrate1, L Raileanu3 and C Munteanu1

1Gheorghe Asachi Technical University of Iasi-Romania, Department of Mechanical Engineering, Blvd. Mangeron, No. 61, 700050, Iasi, Romania
2Gheorghe Asachi Technical University of Iasi-Romania, Department of Materials Science and Engineering, Blvd. Mangeron, No. 41, 700050, Iasi, Romania
3Military School of Air Force “Traian Vuia” Boboc, Buzau, Romania

E-mail: dchicet@tuiasi.ro

Abstract. This study addresses the possibility of using expanded glass to obtain elements with low thermal transfer and stable from a geometric point of view when exposed to high temperatures, which may later be part of a fire-resistant multi-layer element. For this purpose, three types of recipes were designed and produced, which are composed of expanded foam glass spheres bounded with polymeric resin. Subsequently, 3 sets of each sample were subjected to baking: T1 (heating to 700°C, maintaining for 3 hours, oven cooling); T2 (heating to 600 °C, maintaining for 3 hours, oven cooling); T3 (heating to 600 °C, oven cooling). The 4 sets of samples (1 set in initial state and 3 sets of heat treated samples) were exposed for 1 hour at direct flame. It was found that the samples maintained their structural integrity and all three types of material ensure a temperature difference between the side exposed to temperature and the unexposed side higher than 200°C (considered satisfactory according to SREN 1363-1 / 2001).

1. Introduction

Expanded glass foam is a new developed material, with exceptional properties: low specific weight, high strength at compression, dimensional stability, low coefficient of thermal conductivity (λ = 0.07 W/mK), 100% mineral, ecological (made of recycled glass) and safe for the user's health [1]. Thus, the material finds more and more applications on various domains: on the construction materials market (lightweight concrete, plaster and dry mortar, lightweight construction panels) [2 - 4], for automotive parts (cellular composites [5] and syntactic foams [6] for shock absorber structures), in agriculture (soil conditioner for plant substrates [7]) and in other fields (sanitary products, desalinisation compresses for historic masonry rehabilitation etc).

Taking these properties into account, we developed a larger study in which we used expanded glass spheres to create a layer with thermal insulation properties that can be incorporated into an open fire multilayer compound. Thus, starting from a previous experimental study [8], we realized a set of samples that we heat treated for geometric stabilization according to three different graphs, later testing their fire resistance and thermal insulation capacity when exposed to open flame.

2. Materials and methods

The samples tested in terms of fire resistance thermal insulation capacity in this paper were produced using the following materials:

1. quartz sand;
2. commercially available bonding agent: silicon-oxygen polymer resin containing ionic sodium (Na+) components;

3. four types of expanded foam glass spheres produced by Dennert Poraver GmbH, with different grain size (0.04 - 0.125 mm, 0.25 - 0.5 mm, 0.5 - 1 mm, 1 - 2 mm).

For the presented study, three types of recipes were designed and produced, which are composed of expanded foam glass spheres:

- recipe A (quartz sand + expanded glass spheres with a diameter between 0.25-0.5 mm + polymer resin binder) – sample NA15 (figure 1(a)),
- recipe B (quartz sand + expanded glass spheres with a diameter between 0.5-1 mm + polymeric resin binder) – sample NB15 (figure 1(b)),
- recipe C (mixture of spheres with different granulations: 0.04 - 0.125 mm, 0.25 - 0.5 mm, 0.5 - 1 mm, 1 - 2 mm, bound with polymeric resin) – sample S15 (figure 1(c)).

![Figure 1. Samples aspect, after drying in air for 48 hours:](image)
a) sample NA15, b) sample NB15, c) sample S15.

The tests were performed at high temperatures, after a non-standardized test method [9, 10] using a specially designed test stand, presented in figure 2. The test stand is actually an enclosure composed of an external metal frame on which refractory bricks are mounted. Inside, at 2/3 of the side through which the burner is mounted, a wall of refractory bricks is made, provided with a 50x50mm hole in which the samples are mounted. As presented in figures 1 and 2, the test stand use parallelepiped specimens (50x50x15mm), which were made in a special designed mould and dried in a normal atmosphere for 48 hours.
Figure 2. Aspects of the test stand: a) measuring procedure for the sample side not exposed to direct flame; b) measuring procedure for the sample side exposed to direct flame; c) superior view of the test stand.

Subsequently, a set of each sample (one specimen from A, B and C recipe) was subjected to thermal treatments (baking in a laboratory electric furnace) in order to geometrically stabilize the samples. The heat treatment methodology was:
- T1 - heating for 4 hours to 700°C, maintaining for 3 hours and oven cooling;
- T2 - heating for 3 hours up to 600°C, maintaining for 3 hours and cooling with the oven,
- T3 - heating for 3 hours up to 600°C and cooling with the oven.

During the experiments, the temperatures of the samples were measured every 10 minutes (for 1 hour) using a K type thermocouple (-50 ÷ 1300°C) and a TM 902C thermometer, positioned in direct contact with the surface not exposed to flame (see figure 2 (a)). The temperature of the side exposed directly to the flame was measured every 20 minutes, using a small hole nearby the sample, as presented in figure 2(b). Using a gas regulator (see figure 2 (c)), the temperature of the side exposed to direct flame was stabilised between 620 - 650°C, during all tests.

3. Results and discussions
The aspect of the samples after the baking procedure is presented in figures 3 - 5, for each treatment procedure applied.

In an analysis of the three sets of samples, it was observed that the set subjected to T1 treatment underwent structural changes: the S15 sample became more compact and with slight changes in geometry. In the case of samples NA15 and NB15, which have quartz sand in the composition, a slight change in porosity was observed, which increased.
These phenomena can be explained in terms of the temperature at which the sample was heated during the treatment T1 (700°C), which seems to be the threshold at which the expanded glass spheres reach the semi-molten state and change their dimensions (the effect of expansion is lost and suffers volume loss).

In the case of samples subjected to treatments according to T2 and T3 diagrams, the samples did not undergo visible changes, being evaluated as unmodified. Following these observations, it was decided that all samples should be subjected to open flame tests, taking into account that the maximum temperature should be 680°C, but not lower than 600°C.

Because the main purpose of this study is to evaluate the thermal insulation capacity of the analysed samples, after their baking, the interpretation of the results was made taking into account the requirements of SR EN 1363-1 "Fire resistance tests. General Conditions". According to this standard, isolation represents the time in minutes in which the specimen continues to maintain its distinct functions during the test without developing on the unexposed side temperatures which: a) increase the mean temperature above the initial mean temperature by more than 140°C; or b) grow at any point above the initial mean temperature above 180°C [11].

On the samples exposed to direct flame, it was observed that, in the case of all samples consisting exclusively of expanded glass spheres (S15), regardless of the type of baking (T1, T2 or T3), on the contact with the open flame a superficial glass layer was formed, following a vitrification process (see figure 6(a)). The thickness of this layer is between 2-3 mm, but it consists of many gaps and very thin walls of vitrified material. The formation of this layer was observed in the first 30 minutes of the tests, when the heating with the highest speed of the samples on the non-exposed face was also recorded, as seen in figure 7. After this interval, no other change of the side exposed to the open flame was observed, as the heating rate of the samples decreases. We can thus consider that, after the formation of this vitrified foamed layer, the sample has a stable behavior, without being registered it’s burning with smoke emissions or loss of integrity (melting of the sample with material losses). On this set of samples (S15) is also observed the formation of a densified layer in the depth of the sample (located...
below the vitrified one), being visible some large spheres, but also porous effects of melting expanded glass granules, followed by their reduction in volume.

![Images of cross-section aspects of the samples](image)

**Figure 6.** Cross-section aspects of the samples: a) S15 T3 (10x); b) NB15 T2 (15x).

In the case of samples with sand in the composition, regardless of the size of the spheres (NA15, NB15) or the temperature diagram, a behaviour similar to that of the S15 samples was observed: the formation of a superficial layer on the side exposed to open flame, much thinner (1-2mm) but with higher hardness than the rest of the sample. This layer consists of a mixture of sand and semi-molten glass granules, no visible expanded glass sphere being visible in its thickness. However, more and more spheres with different volumes begin to be visible under this layer, as they are at a greater distance from the face exposed to the open flame.

![Graph showing temperature variation](image)

**Figure 7.** Temperature variation on the sides not exposed to direct flame.

The explanation for this phenomenon can be based on the fact that, as the temperature increased, the expansion effect was eliminated, and the glass that initially formed the granules remained spherical, but with smaller dimensions after compaction.

Regarding the insulating effect, the temperatures recorded for the 3 sets of samples are shown compared in figure 7 (for all the samples were recorded temperature differences between 350 - 400°C between the two sides). It is observed that all samples showed the same tendency to heat at high speed.
in the first 30 minutes, followed by a decrease in this speed, sign that the insulation effect becomes stable with the formation of the vitrified layer.

In both cases it is observed that the resulting structures are porous, an aspect that completes the insulating effect by forming an inhomogeneous structure (such as open cell foams) in which air plays an important role along with glass and sand, these two being those that form a rigid structure, non-combustible, resistant to high temperatures.

4. Conclusions
Following these tests, it was found that the samples maintained their structural integrity (in all three cases of heat treatment) and had a satisfactory behaviour because they did not develop open flame and did not register major structural and geometric changes.

It was observed that all three types of material ensure a temperature difference between the side exposed to temperature and the unexposed side higher than 200°C, this variation being considered satisfactory according to SREN 1363-1 / 2001.

5. References
[1] https://www.poraver.com/us/poraver/ (accessed on 22.09.2020).
[2] R. Schreiner et al. 2015 International Journal of Thermal Sciences 95 99-105.
[3] Yu S R, van Onna D V, Spiesz P, Yu Q L and Brouwres H J H 2016 Journal of Cleaner Production 112 690-701.
[4] Adhikary S K, Rudžionis Ž, Vaičiukynienė D 2020 Journal of Building Engineering 31 101399.
[5] Gourav S 2015 J. Civil Eng. Res. 5(3) 53-8.
[6] Su M, Wang H, Hao H, Fiedler T 2020 Journal of Alloys and Compounds 821 153233.
[7] Al-Sahlani K, Broxtermann S, Lell D and Fiedler T 2018 Materials Science & Engineering A 728 80–87.
[8] Mocanita et al 2020 IOP Conf. Ser.: Mater. Sci. Eng. 877 012038.
[9] Mocanita O, Chicet D L, Munteanu C, Istrate B and Oprișan B 2018 IOP Conf. Series: Materials Science and Engineering 444 032011.
[10] Mocanita O, Chicet D, Avram P, Micu C and Munteanu, C 2018 UPB Scientific Bulletin, Series B: Chemistry and Materials Science 81(1) 236.
[11] SR EN 1363-1 / 2001. Fire resistance test. Part 1: General requirements.