Expanded Foam Glass - an Application for Fire Resistant Multilayer Materials

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Abstract. This study is focused on obtaining a fire-resistant multilayer material, which includes in the structure a layer with properties of high temperature resistance and low heat transfer. One of the research directions is focused on obtaining such a layer using expanded glass granules with two different dimensional ranges noted with A (1 - 2 mm) and B (0.25 - 0.5 mm). The target layer was realized with the shape of square plates of 50 x 50 mm, with a thickness of 5 and 10 mm respectively, from a mixture of quartz sand with a polymeric resin as bonding agent in which the expanded glass granules were inserted. The following samples were obtained: P5A and P5B (5 mm thick plates), respectively P10A and P10B (10 mm thickness plates). The samples were analyzed both from the morphological point of view (the emphasis being placed on the structure distribution of the expanded glass granules) and from the point of view of the resistance to high temperatures (by indirect exposure at temperatures between 400 - 600 °C for 3 hours). The satisfactory behavior of the samples during the tests recommends the extension of the researches in this direction, in order to establish the optimal percentage of component elements.

1. Introduction

Expanded foam glass is a material that is gaining more and more ground as a construction material and also in other industrial applications, due to a positive combination of properties: lightweight and pressure-resistance, durable and dimensionally stable, 100% mineral, spherical grain shape, no hazards to health, creamy-white color, ecological - made of post-consumer recycled glass.

Currently, this type of material is used for a wide range of applications, among which can be listed: lightweight concrete [1], plaster and dry mortar, lightweight construction panels [2], fillings, 3D printing with printing beds or with SLS (selective laser sintering), cellular composites [3] or syntactic foams [4] with applications in the automotive field for shock absorber structures, soil conditioner in plant substrates [5], prefabricated sanitary parts or desalination compresses for historic masonry etc.

In addition to the low density that recommend this material for lighter structures, expanded foam glass is also characterized by a very low coefficient of thermal conductivity (λ = 0.07 W / (mK)) and a softening point at a temperature of about 700°C [5]. From the chemical composition point of view, this material belongs to the category of ceramic materials, because is created from a combination of oxides, as follows: SiO₂ (70-75%), Na₂O (10 - 15%), CaO (0, 5 - 5%), MgO (0 - 5%), K₂O (0 - 4%) [5].
Starting from these remarkable properties, in this paper was studied the possibility of obtaining fire-resistant materials, which should include in the structure expanded foam glass granules. This study is part of a larger one, focused on obtaining fire-resistant multilayer materials, in which the thermal insulation role is fulfilled by materials reinforced with expanded foam glass granules. For this purpose, two types of material were made with granules of different sizes, mixed in different percentages with quartz sand and a polymeric binder. Two properties of the samples were studied: fire resistance by exposure to open flame and heat transfer capacity. During the tests, the influence of the size of the expanded foam glass spheres on the fire resistance of the analyzed samples was also evaluated.

2. Materials and methods

The following materials were used to obtain the samples tested in terms of fire resistance in this study:
1. quartz sand;
2. silicon-oxygen polymer resin containing ionic sodium (Na⁺) components, as bonding agent (commercially available);
3. expanded foam glass in spheroidal shape (produced by Dennert Poraver GmbH), with a grain size between 1 - 2 mm (A), respectively with a grain size between 0.25 - 0.5 mm (B). The aspect of the expanded foam glass granules is shown in Figure 1 a, b, for the two categories of granulation.

The materials were mixed in different percentages, as presented in Table 1. The mixture was modelled in specially designed shapes, in the form of plates with the following dimensions: 50 x 50 mm and thicknesses of 10 cm (P10A, P10B), respectively 5 mm (P5A, P5B). After extracting the plates from the moulds, they were left to dry in a normal environment, with a constant temperature (22 ± 2°C) and humidity between 45 - 50%. Figure 2 shows the samples aspect after drying. The homogeneous distribution of the spheroidal granules of expanded foam glass in the whole mass of the sample is observed. All the samples were rigid, with strong connections formed between the components used inside them.

| Sample      | Sand ratio [wt%] | Resin ratio [wt%] | Expanded glass ratio [wt%] | A  | B  |
|-------------|------------------|-------------------|----------------------------|----|----|
| P10A, P5A   | 13.4             | 6.2               | 1                          |    |    |
| P10B, P5B   | 9                | 3.33              | -                          | 1  |    |

Figure 1. The aspect of the expanded foam glass granules with granulation of: a) 1 - 2 mm (A); b) 0.25 - 0.5 mm (B).
For the open flame testing of the samples, a non-standardized test method was chosen, using a stand in the form of a wall, made of refractory bricks, in the middle of which a 50x50mm hole was drilled [6, 7]. In this hole, the tested samples were mounted in turn, ensuring better sealing of the edges so that there is no passage of flames on the other side of the samples, which could lead to errors in measuring the temperature in the concerned area.

In order to obtain conditions as close as possible to reality (e.g., in the case of open flame fire), a flame produced by burning a gaseous fuel was used (butane - propane mixture, 87 - 13%). The burner was mounted at a fixed distance of 10 cm from the mounting surface of the samples in the test stand, as can be seen in Figure 3 a. With the help of a pressure regulator, a constant pressure of the gas was maintained throughout the duration of the tests, so that the temperature recorded at the surface of the sample does not have major variations and could be maintained in the range of 600 - 650°C [8].
The recording of temperature variation during the experiments was performed using a digital thermometer TM 902C, equipped with a K-type thermocouple (-50 - 1300 °C), which was positioned in direct contact with the surface of the sample on the side that was not exposed to direct flame, as can be seen in Figure 3 b.

The open flame exposure tests for samples P10A and P10B respectively were carried out for 60 minutes, the temperatures being recorded as follows:
- once every 30 seconds for the first 20 minutes,
- once every 1 minute, between 21 and 30 minutes,
- once every 5 minutes between 31 and 60 minutes.

The open flame exposure tests for samples P5A and P5B were carried out for 10 minutes, the temperatures being recorded once every 30 seconds.

3. Results and discussions

In this study, the two aspects necessary to characterize the behavior of a material subjected to open flame were followed: structural integrity and thermal insulation capacity. These performance criteria are regulated by SR EN 1363-1 "Fire resistance tests. General Conditions": sealing and insulation. Sealing is the time in minutes in which the specimen continues to maintain its distinct functions during the test without resulting in sustained flame. Isolation is 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 [9].

If we analyze the behavior of the samples from the point of view of the first performance criterion - the sealing capacity, we can claim that the samples P10 A, respectively P10 B had a satisfactory behavior, because none of them lost their structural integrity and did not burned with flame after the tests they were subjected to. Regarding the P5A and P5B samples, respectively, they did not burn with an open flame during the tests, but they underwent geometric changes.

Figure 4 shows the aspect of the sample P10A, being observed that on the side exposed to direct flame a layer with an expanded appearance was formed, which still has rigidity and mechanical strength. The aspect of the side that has not been exposed to the flame is similar to that of the sample in its initial state, lighter in color due to dehydration and vitrification of the binder, but without major changes or destruction of the surface. These observations are supported by the cross-section aspect of the sample (Figure 4c), which show a slight damage of the expanded foam glass granules that have become brittle, but a structure of the sample still homogeneous and which has not been affected differently in thickness.

The same observations can be made in the case of sample P10B, the aspect of which is shown in Figure 5. However, a less expanded aspect of the surface exposed to direct flame is observed (Figure 5a), while the aspect of the side that was not exposed to the flame is very similar to that of the initial sample (Figure 5b). The cross section of the sample (Figure 5c) shows that no differentiated transformations occurred on the thickness of the sample, that were produced only those specific to the dehydration and vitrification of the binder, and the expanded glass granules were not affected so as to break at sectioning.

However, the geometry of the samples with a thickness of 5 mm was affected, their appearance being presented in Figure 6 a, b (P5A), respectively Figure 7 a, b (P5B). In both cases, the same expanded aspect of the surface exposed to direct flame is observed (Figure 6a, Figure 7a), which is present in this case on the sides that were not exposed to flame (Figure 6b, Figure 7b). Also, a different curvature of the samples in the central area is observed: towards the flame in the case of the P5A sample, respectively in the opposite direction to the flame in the case of the P5B sample.
Figure 4. The aspect of the P10A sample after open flame exposure for 60 minutes: a) the aspect of the side exposed to direct flame, b) the aspect of the side that has not been exposed to the direct flame, c) the aspect of the cross-section of the sample.

Figure 5. The aspect of the P10B sample after open flame exposure for 60 minutes: a) the aspect of the side exposed to direct flame, b) the aspect of the side that has not been exposed to the direct flame, c) the aspect of the cross-section of the sample.
Figure 6. The aspect of the P5A sample after open flame exposure for 60 minutes: a) the aspect of the side exposed to direct flame, b) the aspect of the side that has not been exposed to the direct flame.

Figure 7. The aspect of the P5B sample after open flame exposure for 60 minutes: a) the aspect of the side exposed to direct flame, b) the aspect of the side that has not been exposed to the direct flame.

In the case of evaluating the second performance criterion, that of thermal insulation (heat transfer), comparative graphs of the temperatures recorded during the tests were made (Figures 8 and 9), both on the sides that were not exposed to direct flame and on the side exposed to the flame.

Figure 8. Temperature variation on the sides not exposed to direct flame of samples P10A and P10B in comparison with the temperature on the side exposed to direct flame.
At the analysis of the first set of samples - the one with a thickness of 10 mm - it is observed that the recorded temperatures (on the sides that were not exposed to direct flame) are similar for the two types of samples, the maximum temperatures being around 240°C (Figure 8). There was a faster increase in temperature to 210°C (in the first 30 minutes) followed by a slow increase of about 1°C / min until the end of the test. Compared to the temperature of the side exposed to the flame, a temperature difference between 350 - 400°C is observed, this being within the limit of at least 180°C imposed by SR EN 1363-1, fact for which we can say that the samples P10A, respectively P10B successfully meet criterion 2 - isolation.

![Figure 9](image_url). Temperature variation on the sides not exposed to direct flame of samples P5A and P5B in comparison with the temperature on the side exposed to direct flame.

Regarding the evaluation of the fulfilment of criterion 2 in the case of the thinner samples (P5A, respectively P5B), from the variation graph of the temperatures registered during the test, a much rapid increase of the temperature is observed. Values close to 200°C were reached after the first 3 minutes in the case of sample P5A, while in the case of sample P5B there was a rapid increase of the temperature in the first 2 minutes (up to about 142°C) followed by a lower speed increase to a temperature of 201°C recorded at the end of the test. However, these values must be interpreted with caution due to the bending phenomenon of the samples, produced in the first 4-5 minutes of the tests, which could have induced measurement errors, although the contact of the thermocouple with the surface was maintained throughout the test sample.

4. Conclusions
In this paper, the fulfilment of two performance criteria of two types of materials subjected to open flame tests was studied: structural integrity and thermal insulation capacity (heat transfer), regulated by SR EN 1363-1 “Fire resistance tests.” These two criteria were also analysed in terms of the influence of the size of the expanded foam glass spheroidal granules used in the composition of the samples, but also in terms of the wall thickness of the samples tested at fire.

Following the performed tests, the following conclusions were drawn:
✓ both samples with a thickness of 10 mm (P10A, respectively P10B) had a satisfactory behaviour in terms of the first performance criterion (“sealing”), because they did not develop open flame and did not register major structural and geometric changes;

![Graph](image_url).
✓ both samples with a thickness of 10 mm had a satisfactory behaviour in terms of meeting the second performance criterion ("insulation") because, between the two sides, there were recorded temperature differences between 350 - 400°C;
✓ the samples with a thickness of 5 mm did not have a behaviour that could be considered relevant from the point of view of the isolation criterion, due to the curvature of the surface during the tests. However, the samples did not ignite and did not allow the flame to pass to the other side, behaviour that can be considered satisfactory for the evaluation from the point of view of the first criterion ("sealing");
✓ from the point of view of the influence of the size of the expanded foam glass granules on the behaviour of the two materials, we can specify that the smaller size granules (type B) ensured a better compactness of the material during the tests, the samples being less affected by the expansion phenomenon as a result of the transformation at high temperatures of the granule material and of the binder.

5. References
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