The effect of expanded perlite on fired clay bricks

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Abstract. Nowadays stricter energy regulations are compelling us to further improve the thermal insulation performance of current building materials. In this study we investigated the possibility of improving the thermal insulating performance of fired clay bricks. In our work we used two types of additives: sawdust, which is a general additive, and expanded perlite, which is typically a synthetic additive based on SiO$_2$ and Al$_2$O$_3$. Sawdust and expanded perlite in amounts varying between 3.35-6.5 wt% were mixed into a clay masses to prepare test samples by pan mill. The moisture content of the clay masses was 25 wt%. Samples were prepared using a laboratory vacuum extruder, after which they were dried, and then sintered at 880 °C. The fired specimens were measured for firing shrinkage, water absorption, bulk density, and compressive strength. Furthermore, we determined the thermal conductivity of the specimens. The purpose of our research was to examine the usability of expanded perlite as an additive in brick manufacturing, and also to compare the results with sawdust, one of the most popular additives. In addition, measurements were made using the two additives together.

1. Introduction

Fired bricks, which consist of clay, water and other additives, are one of the oldest building materials. The density, mechanical strength and color of the fired bricks depend on the mineral composition of the raw materials and on the firing temperature used [1, 2]. Brick is basically a solid ceramic with high mechanical strength, and additionally it also has low thermal insulation properties. Pore-forming additives, which burn out, are added to a clay mass to improve thermal insulation during the firing process, thereby increasing the porosity in the burnt clay matrix. Sawdust is the most widely used additive; though research is being carried out into the use of other additives such as sunflower kernels, rice hulls, and the by-products of winemaking [3-7]. These additives are removed from the clay mass during heat treatment, causing pores to form and resulting in a significant reduction in the compressive strength of products made this way. Several studies have been published demonstrating that the amount of these additives may not exceed 10%, due to the greatly reduced compressive strength [8-10]. For this reason, we chose expanded perlite, which doesn’t burn out and is stable up to 900 °C, and therefore was expected to reduce compressive strength to a lesser extent. In addition, due to its porous structure, it improves the thermal insulation capacity of the samples.

Perlite is nothing more than a hydrated volcanic glass which includes water in its crystalline structure. Perlite has a high SiO$_2$ content and a low softening point. Taking advantage of these properties, this easy to prepare additive can also be used in the construction industry [11, 12]. Extracted perlite rock is heated at 900-1200 °C by sudden heating, and as a result it increases by 5 to 20 times from its original volume [13, 14]. As a result of the volume increase, perlite is converted into
a low density (40-110\text{kg/m}^3) cellular material called expanded perlite. Due to its open cell structure, the produced structure has excellent insulation properties, high porosity, and also good sound insulation properties. [15-17]. 65% of the perlite produced today is used in the construction industry. Perlite is an excellent additive for concrete and brick production because of its high heat and sound insulation properties [18]. Expanded perlite is used in light-weight, insulating plaster and ceramic products to fill cavities and thereby improve the energy properties of building materials [19]. Thus, sawdust and expanded perlite were used as pore forming additives in varying amounts for the experiments.

2. Materials and methods

2.1. Characterization of the raw materials

A mixture of gray (GC) and yellow (YC) clay having a 1:1 ratio was used for the preparation of a clay mass. The mineral composition of the clays was determined by X-ray powder diffraction (Rigaku Miniflex II, Cu K\(_\alpha\), 2\(\theta\) range from 3 to 90\(^\circ\)). The XRD patterns and results are presented in Figure 1 and Table 1, respectively. The mineral composition of the clays was measured. It showed that yellow clay contains 44.9\% clay minerals and gray clay 34.5\% clay minerals. A reference mixture using the two clays without additives was prepared and analyzed for particle size via hydrometer measurement. The results showed that the fraction of the clay mass below 2 \(\mu\text{m}\) was 40.5\%wt\%, confirming the amount of clay minerals obtained from XRD.

![Figure 1. XRD patterns of raw materials](image)

**Table 1.** Mineral composition of raw materials and particle size distribution of clay mixture

| Raw. mat. | Q | I | M | Al | SM | G | K | IS | R | Cl | MI | C | O | D | AM |
|-----------|---|---|---|----|----|---|---|----|---|----|----|---|---|---|----|
| GC        | 33.1 | 21.9 | 9.2 | 9.0 | 5.7 | 0.0 | 4.5 | 0.9 | 0.8 | 3.9 | 2.1 | 1.0 | 0.0 | 0.0 | 8.0 |
| YC        | 36.9 | 18.4 | 4.8 | 12.2 | 2.1 | 0.7 | 3.4 | 0.8 | 0.7 | 6.7 | 0.6 | 5.4 | 1.5 | 2.8 | 3.0 |
| Particle size | 1-2mm | 0.5-1mm | 0.25-0.5mm | 125-250\(\mu\text{m}\) | 63-125\(\mu\text{m}\) | 32-63\(\mu\text{m}\) | 16-32\(\mu\text{m}\) |
| Mass [wt\%] | 0 | 0.1 | 0.5 | 3.2 | 10.7 | 11.5 | 11.1 |
| Particle size | 8-16\(\mu\text{m}\) | 4-8\(\mu\text{m}\) | 2-4\(\mu\text{m}\) | 1-3\(\mu\text{m}\) | <1\(\mu\text{m}\) |
| Mass [wt\%] | 9.7 | 7.6 | 5.0 | 5.0 | 35.5 |

(Q: quartz; I: illite; M: muscovite; A: albite; SM: smectite; G: goethite; K: kaolinite; IS: illite-smectite; R: rutile; Cl: Chlorite; MI: microcline; C: calcite; O: orthoclase; D: dolomite; AM: amorphous content)

Two additives, sawdust (S) and expanded perlite (EP), were used to reduce the density of the samples. The particle size distribution of sawdust is shown in Figure 2. The type of expanded perlite used was ANZO P2. The amount of additives compared to the weight of the clay mass was from 3.35 to 6.5\%wt\%, being 23-35V/V\% for sawdust and 30-45V/V\% for expanded perlite.
2.2. Mixture preparation, mixture characterization, and fire brick production

Three different clay mass series were arranged for the preparation of the samples. In the first two series, the two additives were separately mixed into the clay mass, but in the third we varied the amount of the expanded perlite that was mixed with a fixed amount of sawdust. The exact formulations of the mixtures are detailed in Table 2. Employing a formula used by a brick factory in Hungary where the base amount of sawdust is 3.35%, we also chose this to be our base amount. The clays and sawdust were dried for 48 hours at 50 °C, and then we prepared the masses with pan mill, as shown in Figure 3. In each case, the dry ingredients were first homogeneously blended by means of the apparatus, after which we gradually added the water quantity necessary for shaping. The moisture content was 25wt% on a dry basis for each clay paste. The reference sample was a mixture of clay without any additive.

The appropriately homogenized clay paste was hermetically closed, and after 24 hours of rest, cylindrical specimens, 24 mm X 50 mm, were prepared using a laboratory vacuum extruder (KEMA PVP 5 / s). The shaped samples were placed in a drying tray and dried to constant weight. The samples were fired at 880 °C.

| Preparation 1 | Sawdust | Preparation 2 | Expanded perlite | Preparation 3 | Sawdust | Expanded perlite |
|---------------|---------|----------------|-----------------|---------------|---------|-----------------|
| S1            | 3.35    | EP1            | 3.35            | SEP1          | 3.35    | 3.35            |
| S2            | 3.5     | EP2            | 3.5             | SEP2          | 3.35    | 3.5             |
| S3            | 4.5     | EP3            | 4.5             | SEP3          | 3.35    | 4.5             |
| S4            | 5.5     | EP4            | 5.5             | SEP4          | 3.35    | 5.5             |
| S5            | 6.5     | EP5            | 6.5             | SEP5          | 3.35    | 6.5             |

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3. Results and discussion

3.1. Drying and firing shrinkage

The specimens were dried in the open air for 24 hours, and then at 105 °C in a laboratory oven to constant weight. The diameter and height of the samples were measured in both the raw and dried states, and based on these measurements, the percentage of drying shrinkage was calculated. For each mass, the average value of 10 samples was taken. Drying shrinkage decreased with the addition of additives, as the average drying shrinkage of the additive-free samples was 16% (Fig. 6). Based on our results, it can be said that the use of expanded perlite alone reduced the drying shrinkage the greatest extent. The firing shrinkage also showed a similar trend (Fig. 7). Even in this case, the samples made of expanded perlite masses showed the smallest burning shrinkage. The average shrinkage of the reference specimens was 15%, which can be reduced to 8% by mixing 6.5 wt% expanded perlite.

![Figure 6. The effect of additive on Drying shrinkage](image1)

![Figure 7. The effects of additive on Firing shrinkage](image2)

3.2. Bulk density and water absorption

Based on Archimedes' Law, we used a hydrostatic method to measure the density of the samples. In this case, measurements were performed on 5 burnt samples per set dried at 105 °C to constant weight. Figure 8 shows the results of the test. The highest density, 1.8551 g/cm³, was found in the additive-free samples. With the incorporation of additives, the bulk density of the samples showed a decrease in all cases. We found that S5 and SEP5 showed almost the same decrease in body density, 15% below the reference, while EP5 was 11% below the reference.

The water absorption capacity was calculated based on the average value of 10 samples. The fired samples were placed in a container filled with water, the water was heated to boiling, and then subsequently heated for 3 h. The amount of water present in the open pores was calculated from the dry and water-saturated masses of the specimens. Figure 9 shows that the swollen perlite has a lower water absorption capacity than that of the sawdust samples.
3.3. Compressive strength and Thermal conductivity

Compressed strength tests were performed on the 24 mm x 50 mm burnt samples. The results obtained (Fig. 10) clearly show that expanded perlite reduced the compressive strength of the specimens less than sawdust did.

The heat conductivity coefficients of the S and SEP series samples were determined with the help of a transient plane source device (C-Therm TCi Thermal Conductivity Analyzer). Results showed that heat conductivity coefficient can be lowered down to 0.14W/mK (Figure 11.) by using sawdust or a mixture of sawdust and perlite. Using an increased amount of sawdust, from 3.35wt% up to 6.5wt%, or using a mixture consisting of 3.35wt% sawdust and 6.5% perlite, both resulted in the same conductivity value. This means a decrease of 85% relative to the reference value of 0.83W/Mk. However, taking into account the compressive strength values, S5 showed only 16MPa compared to the reference 34MPa, while SEP5 containing perlite achieved 22MPa.

4. Conclusions

Based on our investigations, we found that sawdust and expanded perlite both have a positive effect on drying shrinkage, and this is important from a technological point of view, as it reduces the sensitivity of the products to cracking. The same can be said for firing shrinkage, since 6.5wt% of expanded perlite reduced it from 16% to 8% while the same amount of sawdust was reduced to 9%. The bulk density for samples containing 6.5wt% sawdust (S5) as well as for those containing a mixture of 3.35wt% sawdust and 6.5wt% perlite (SEP5), when compared to the reference sample, were 15% lower. The specimens containing 6.5wt% expanded perlite showed an 11% reduction. In the case of...
water absorption, increasing the amount of expanded perlite does not increase the water absorption; although this is not the case in the samples containing sawdust. It follows that expanded perlite enhances the frost resistance of the products. The most obvious difference between mixing sawdust and swollen perlite is that by increasing the amount of the perlite, the compressive strength is reduced to a lesser extent than when mixing with sawdust. The reference 34MPa value decreased to 16MPa with 6.5wt% sawdust, while samples with 3.35wt% sawdust and 6.5wt% swollen perlite showed compressive strengths of 20MPa; however, a thermal conductivity of 0.14W / mK was the same in both cases.

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