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# Frost resistance of clay roofing tiles: Case study

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**Abstract**

In order to give required protection of the buildings, clay roofing tiles should be resistant to freezing conditions. In the present study, clay roofing tiles were fired at different temperatures. Afterwards, direct and indirect test methods were used to evaluate their frost resistance. The direct method in standard EN 539-2 was applied, ASTM C 1167-03 was used for indirect methods, and Maage factor was calculated from Hg-porosimetry curve. It was confirmed that the temperature of firing is the main influential parameter as it affects the porosity of a ceramic body. The comparison between indirect and direct methods of prediction and test of frost resistance has also shown good correlation.

*Keywords:* Frost resistance; Clay roofing tiles; Hg-porosimetry; Flexural strength

## 1. Introduction

Frost resistance of ceramic products is a decisive factor for their durability. Water permeates into the pores of ceramic materials and, in the case of exposure to cold weather, it can freeze. The local high stress arises in surroundings of the pores and it can cause micro-cracks and fracture of material. The reaction of ceramic products to frost depends on several parameters, such as raw material and its composition, firing process, and properties of finished products, such as pore size distribution, pore shape, and strength of its structure [1,2].

For the prediction of frost resistance many standardized methods which simulate natural conditions have been developed. Besides them, there are also indirect methods which give prediction on frost resistance on the basis of knowledge how freezing phenomena is influenced by distribution of porosity, degree of saturation, rate of freezing, etc.

The direct freezing–thawing method for clay roofing tiles, which is widely used in Europe, is EN 539-2 [3], prescribing five different methods for different climatic regions. All methods specify that samples first be soaked in water and then exposed to a number of freezing–thawing cycles. After a certain number of cycles (depends on the method selected) samples, not showing significant damages, are labelled as frost resistant.

The ASTM C 1167-03 [4] indirect method is fast and simple for execution, providing a prediction of frost resistance through the saturation factor S. This factor is the ratio between water absorption after 24 h of soaking in cold water and the water absorption after 5 h of boiling.

Classification of resistance to freezing–thawing is as follows:

- $S < 0.74$ – high probability for material to be frost resistant in severe climatic,
- conditions $0.74 < S < 0.84$ – uncertain zone of frost resistance, and
- $S > 0.84$ – low probability for material to be frost resistant.

The indirect method of wide recognition is also Maage factor [5,6] of frost resistance prediction. The factor is based on experimental results and on a statistical model with two main variables: the total volume of pores (PV) and the share of pores at certain pore diameter, which is greater than 3 μm (P3). Maage [5,6] proposes the following equation, which gives factor of frost resistance DF:

$$\mathrm{DF} = \left(\frac{3.2}{\mathrm{PV}}\right) + (2.4 \times \mathrm{P3}), \qquad (1)$$

where PV represents the pore volume as the volume of intruded Hg ($\mathrm{cm^3/g}$), and variable P3 represents the share of pores bigger

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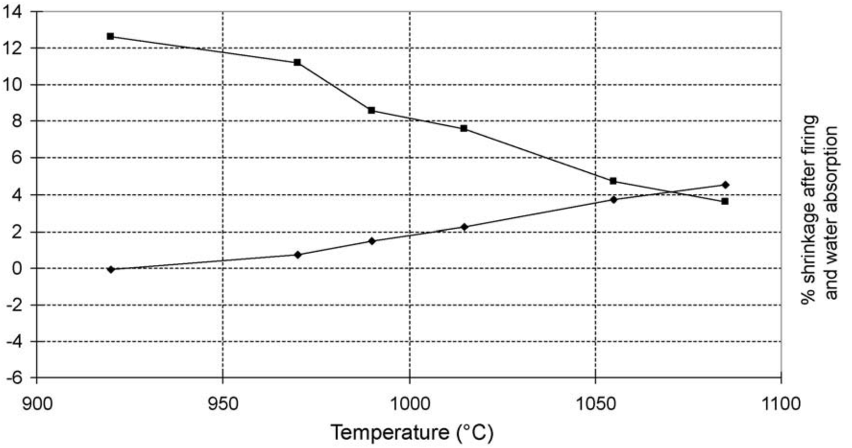

Fig. 1. Dependence of water absorption and shrinkage on firing temperature.

than 3 μm. It has been further proposed the following classification:

- DF > 70 – high probability for material to be frost resistant in severe climatic conditions,
- 55 < DF < 70 – uncertain zone of frost resistance, and
- DF < 55 – low probability for material to be frost resistant.

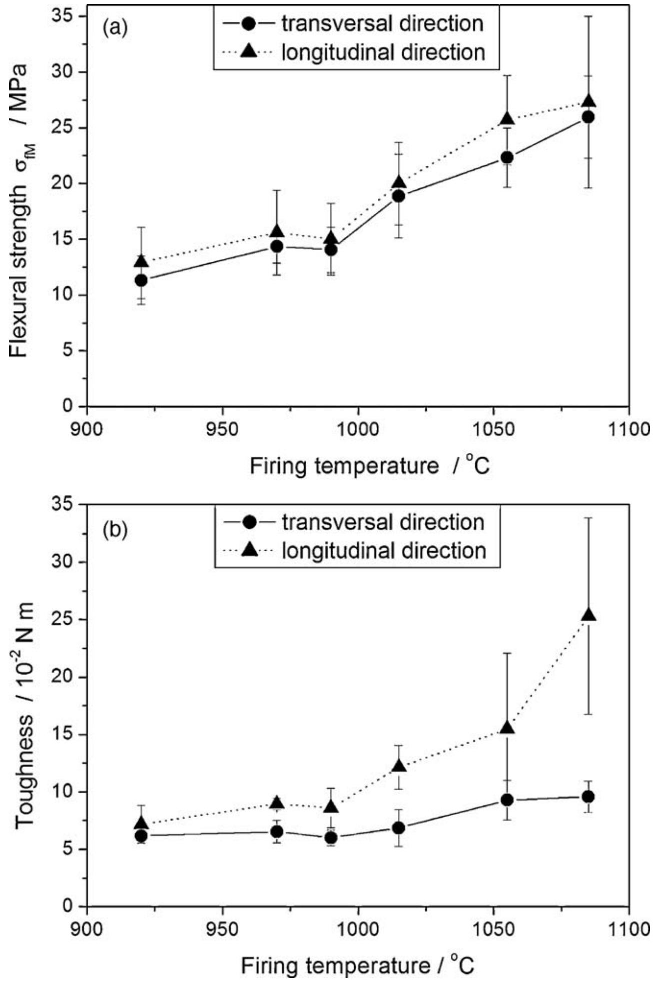

Fig. 2. Dependences of (a) flexural strength (maximum flexural stress sustained by the sample during a bending test) and (b) toughness on firing temperature (transversal direction is alongside the extrusion and longitudinal direction is perpendicular to the extrusion, respectively).

Koroth et al. [7] also developed a durability index based on the assumption that the share of pores greater than 3 μm play a crucial role in frost resistance of clay bricks, while Franke and Bentrup [8,9] proved on 40 different types of bricks (new and ancient) that the most important factor is the mean pore radius $r_{50\%}$, (assigned to 50% filling of the pore volume), where limit for resistant bricks lies at or above 1 μm.

Besides porosity, for achieving frost resistance of clay roofing tiles, mechanical properties represent an important factor; if they are high enough, mechanical properties can withstand pressure applied by freezing water. The influence of the maturing temperature on porosity and consequently on mechanical behaviour of ceramic bodies was studied by Jordan et al. [10], but there is no literature data available for the correlation between mechanical properties and frost resistance for roofing tiles. The valid ASTM C62-08 [11] for bricks proposes that (a) brick resistant to severe weathering (SW) should have minimum compressive strength of 20.7 MPa (b) those resistant to moderate weathering (MW) 17.2 MPa, and (c) those resistant to negligible weathering (NW) at least 10.3 MPa.

In practice, it is recommended to use both types of methods (direct and indirect ones) and to set the correlation for certain type of raw materials. With regard to these results, producers can later decide whether to use the selected method for regular checks in the production control process or not.

The aim of our work was (a) to determine the temperature range of firing in which the selected clay based products are frost resistant, (b) to compare the use of direct and indirect methods used for the determination of frost resistance and (c) for specific type of clay products establish a correlation between both types of methods.

## 2. Experimental

In order to prepare specimens fired at different temperatures, dry samples of clay roofing tiles were taken from regular production and fired in laboratory (simulating the firing process of regular production) at different temperatures: 970, 990,