Clay Boards as a fire protection layer – State of the art

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Abstract: This paper presents an overview of current research and knowledge when using clay as fire protection layers in timber structures and a comparison to the current standardisation regarding fire safety of timber structures. In Germany, fire safety requirements for load-bearing and separating elements in timber constructions consider standard fire resistance (REI) and for multi- storey timber buildings also additional criteria such as protection ability of linings for timber elements. Typically, gypsum boards are used to meet these requirements. However, industrially manufactured clay boards are emerging as a promising alternative or complement to conventional protection systems. This paper reviews current standards and regulations, showing that existing guidelines underestimate the fire protection performance of clay boards, as they are based on data derived from clay plasters. This leads to the necessity of further investigations to complement the current standardisation.

Keywords: clay boards, clay plaster, fire protection system, timber structures, fire design

1 – Introduction

Fire protection layers for timber structures typically consist of gypsum boards. The boards for enhanced fire protection consist primarily of a mixture of technical and natural gypsum and mineral fibres [1]. The most used technical Gypsum is the REA-gypsum, a byproduct of flue gas desulphurisation in coal combustion in power plants, which provides around half of the used gypsum in Germany [2]. Considering Germany's ongoing energy transition, which aims to reduce reliance on coal, a long-term reduction in the use of REA-gypsum can be expected [3]. One potential alternative is the use of clay boards, either alone or in combination with gypsum boards, to maintain adequate fire protection while reducing the environmental impact.

Therefore, this publication provides an overview of the regulatory background for the use and necessity of fire protection layers in Germany. It is followed by a summary of the current state of scientific research and standardisation concerning the application of clay as a fire protection material.

2 – Regulatory Background

To understand the necessity of fire protection systems it is crucial to differentiate between the classic fire resistance REI, including the criteria Load-bearing capacity (R), Integrity (E) and Insulation (I), and the additional regulatory requirements arising from building codes for multi-storey timber structures concerning the protection ability of linings and the start time of charring (t_{ch}).

Catalogues already list possible building elements using clay boards, ensuring 30, 60, or 90 minutes of Integrity and Insulation [4]. Elements with loadbearing and separating requirements lined with clay products under fire exposure can be designed using the next generation of EN 1995-1-2 [5].

In Germany, timber buildings in building classes 4 and 5 require a fire protection lining. This lining must delay the start time of charring by 30, 60, or 90 minutes, depending on the size of the fire compartment, the type of structural element, and the building class. Furthermore, material specifics concerning the fire protection linings requires the need to consist of non-combustible material (class A1/A2) [6]. From a purely building code perspective, this limits the use of clay boards to the four currently available board types listed in Table 1.

Table 1: Clay boards in fulfilling required reaction to fire classification

Clay board producer	Density ρ [kg/m³]	Class
LEMIX [7]	1450	A2-s1 d0
WEM [8]	1560	A2
Leipfinger-Bader	1850	-
Rapido Lehmplatte [9]	1413	A2

3 – Clay as fire protection material

3.1 – State of scientific knowledge

In [10] model scale furnace fire resistance tests were conducted using various plaster systems reinforced with natural fibres (hemp, cattail, and straw) applied on reed mat substrates. The plasters density ranged between 1600 – 1800 kg/m³. The tests were performed horizontally with an exposed area between 0.22 and 1.5 m² and under standard fire exposure. It can be derived that clay plaster thickness is a crucial factor, and protection time increases in proportion to the layer thickness. Among the fibre types, hemp and straw, hemp-reinforced clay plaster postponed the start time of charring 2.5 minutes longer than straw reinforced plaster. This corresponds to an increase of about 14 %. In [11], a comparison between horizontal (ceiling) and vertical (wall) orientations of the plaster system suggests that a vertical orientation improves the basic protection time. However, due to variations in plaster thickness and reinforcement configurations, further investigation is needed to confirm this effect.

Investigations presented in [12] examined various board materials, including hemp, wood and clay. The clay boards incorporate different additives. One consists of hemp and glass fibre, the other of perlite, reed stems, hemp, jute mesh, cellulose fibre, and starch, and the third one uses an inorganic binder. All clay boards had a density of around 700 kg/m^3. Small-scale fire experiments (100 × 100 mm) were conducted using a cone heater of a cone calorimeter, with 50 mm thick timber specimens as backing material and subjected to a predetermined heat flux of 50 kW/m^2 for 20 minutes followed by 20 minutes with a heat flux of 75 kW/m^2. Despite significantly lower density as clay plasters, the start time of charring occurred within a similar time range. The use of an inorganic binder enhanced the fire protection ability significantly.

In [13] large-scale fire tests were conducted on a vertically oriented timber frame backed with insulation (TF) and a solid timber (ST) construction with dimensions of 3 × 3 m. In both tests, the protection layer consisted of 22 mm Lemix clay boards. Temperature development was measured behind the clay boards. A temperature of 300°C was measured behind the clay boards after 32 minutes (timber frame) and 27 minutes (solid timber). This contradicts common findings, which suggest that fire protection linings backed by solid timber exhibit a later start time of charring compared to those backed by insulated timber frame constructions [14].

3.2 – State of the Art

The revision of Eurocode 5 includes design parameters for fire protection with clay plaster and boards. The approach for determining the basic protection time, now incorporated into the standard, was originally derived for clay plaster in [15] (see equation (1)).

$$\mathrm{t_{prot,0,i}} = 1{,}1 \cdot \mathrm{h_i} - 6{,}6 \qquad (1)$$

$t_{prot,0,i}$	[min]	basic protection time
h_i	[mm]	lining thickness

In the case of clay plaster and clay boards, the sum of the protection times of the different protection linings equals to the time of charring, as the time of failure is always higher than the time of charring, leading to equation (2) (see 5.4.2.3 (12) in [5]). Keeping in mind, this approach is only valid within specific material thickness limits, which are 40 mm for wall applications and 20 mm for ceilings and if the plaster/board is applied on solid timber or panelling. Additionally, as equation (1) was derived for clay plaster, it only applies to densities higher than 1600 kg/m^3. This excludes most clay boards currently on the market (see Table 1).

$$\mathrm{t}_{ch} = \sum t_{prot} \qquad (2)$$

t_{ch}	[min]	start time of charring
t_{prot}	[min]	protection time

3.3 – Comparison

Figure 1 compares the literature test results with the design equations given in [5]. As the formula was derived for clay plaster, there is a good fit with the provided data. Also, the clay boards with h=14 mm and a significantly lower density correlate well with the design equation. It must be noted that the test specimens in [12] were much smaller and heated from above with different test conditions, so no fall-off was possible. Nevertheless, it is notable that the results are comparable despite the density being far below 1600 kg/m^2. The 22 mm thick clay boards with low- and high-density, improve the protection time compared to lime plaster.

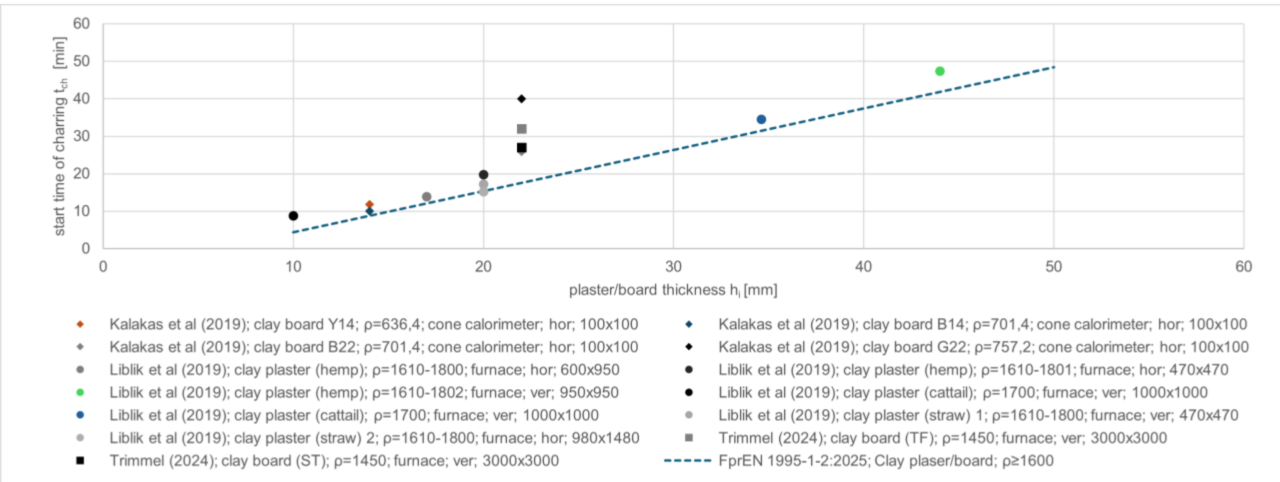

Figure 1: Start time of charring in reference to clay plaster/board thickness in literature and design parameters in [5] providing information about density (ρ), testing method (furnace, cone calorimeter), orientation (horizontal, vertical) and specimen size (mm)

4 – Outlook

The results indicate significant potential and a clear need for further research to establish clay boards as effective fire protection layers. Current standardized calculation methods—initially developed for clay plaster—are not directly applicable due to material density and composition differences. Fire tests have shown longer protection times for clay boards than predicted by the design equations in [5], presenting the need for complementary calculation approaches

In this context, the newly launched research project Be**clay**dung involves large-scale fire tests to improve the predictive accuracy of fire protection times for clay boards. The project's overarching objective is to facilitate the broader application of clay boards as fire protection system across all building classes in Germany, either as a standalone solution without additional linings or in combination with commonly used fire protection systems.

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