Summary report on the research project

Optimization of the design and manufacturing processes of highly fire-retardant wood panel elements from the safety, technical and commercial point of view (Optimization K60)

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1 Objective of the research task

The objective of the research project was the improvement of commercial quality (process optimization) in medium-rise wood-panel constructions from the point of view of Safe Building (fire protection). It was not until the amendment of the MBO in 2002 that a new market for buildings up to 13 m in height was opened up for timber construction. The only reason this became possible was that a research project had demonstrated that, provided certain design requirements were complied with, the fire risk was no higher than with buildings of a non-combustible solid construction. The central part of the design requirements is that the load-bearing timber structure be protected against inflammation for a fire duration of 60 minutes by means of a non-combustible cladding. The fire-protection cladding must be dimensioned such that an average temperature of 270 °C is not exceeded at the surface of the wooden components. The fire-protection cladding is usually attached to the timber structure by means of metal fixing devices such as staples or screws. Since metal has very good thermal conductivity, in the event of a fire heat is conducted through the fixing devices into the timber structure and thus considerably speeds up carbonization. This means that the non-combustible fire-protection cladding has to be overdimensioned and comparatively uneconomic designs are the result. Other fastening methods such as adhesive bonding would be much more suitable as regards thermal conductivity but would generally be regarded as critical on account of the combination of wood and the mineral plate material. One objective of this research project - since positive results had been obtained in other investigations with bonded joints - was to replace the metal fixing devices by glued joints and thus find some considerably more commercially attractive solutions for the fire-protection cladding. In addition to examining the possibility of using adhesives, the thermal conductivity of various conventional fixing devices was also investigated. Installation techniques were worked out here which made a covered attachment of the fire-protection cladding possible. During the course of this investigation a fire-protection risk analysis was also carried out which clarified whether carbonization spots could be tolerated in the vicinity of screws.

In addition, commercially feasible connector detailing was also to be designed, particularly for bracket loads.

2 Permissible discoloration in the vicinity of the fixing device

In the case of a wall structure made of wood the greatest thermal input in the event of a fire occurs via the fixing devices used to attach the fire-protective cladding to the timber structure. These critical points will be of decisive importance in the dimensioning of the entire fire-protection cladding if carbonization is to be prevented here too for the full fire resistance period. This requirement means that in the case of a cladding with a $K_2$60 classification, consisting of 2 x 18 mm gypsum boards, an average temperature of only around 140 °C on average will be found on the surface of the wood in the 60th minute. The ‘no carbonization’ requirement is however interpreted differently by the various testing institutes throughout Europe - in other words, no uniform test criteria are applied.

Another objective of this research project was to express in specific terms the requirements relating to carbonization or discoloration in the vicinity of metal fixing devices while taking into consideration the protective purpose of the fire-protection cladding.

For this reason it was necessary to clarify the question as to what is regarded as carbonization within the meaning of the model timber building code and of the DIN EN 14135 test standard and what can be regarded simply as a discoloration.

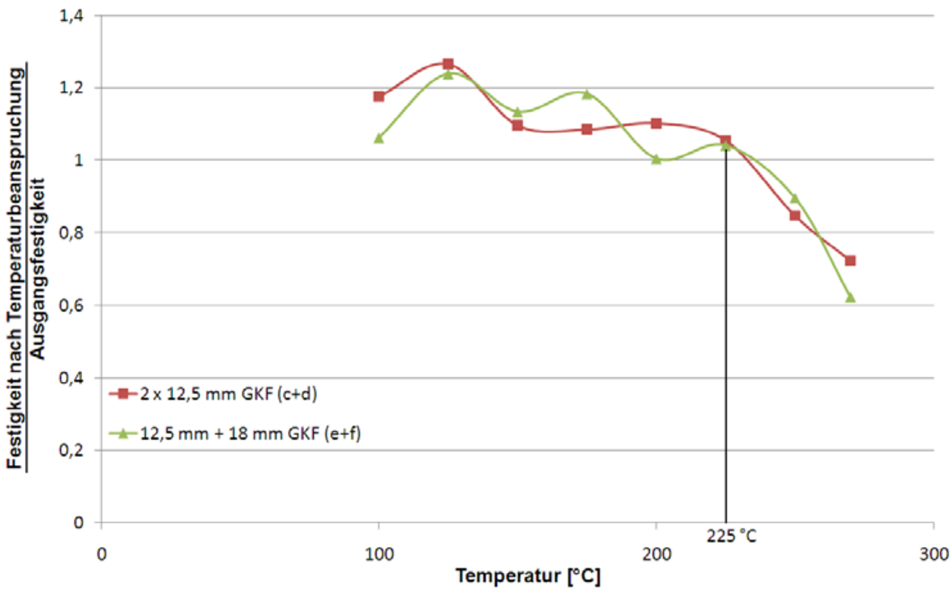

Fig. 1: Temperature-dependent screw extraction resistance

Key:
Festigkeit nach Temperaturbeanspruchung = Strength following exposure to high temperature
Ausgangsfestigkeit = Initial strength

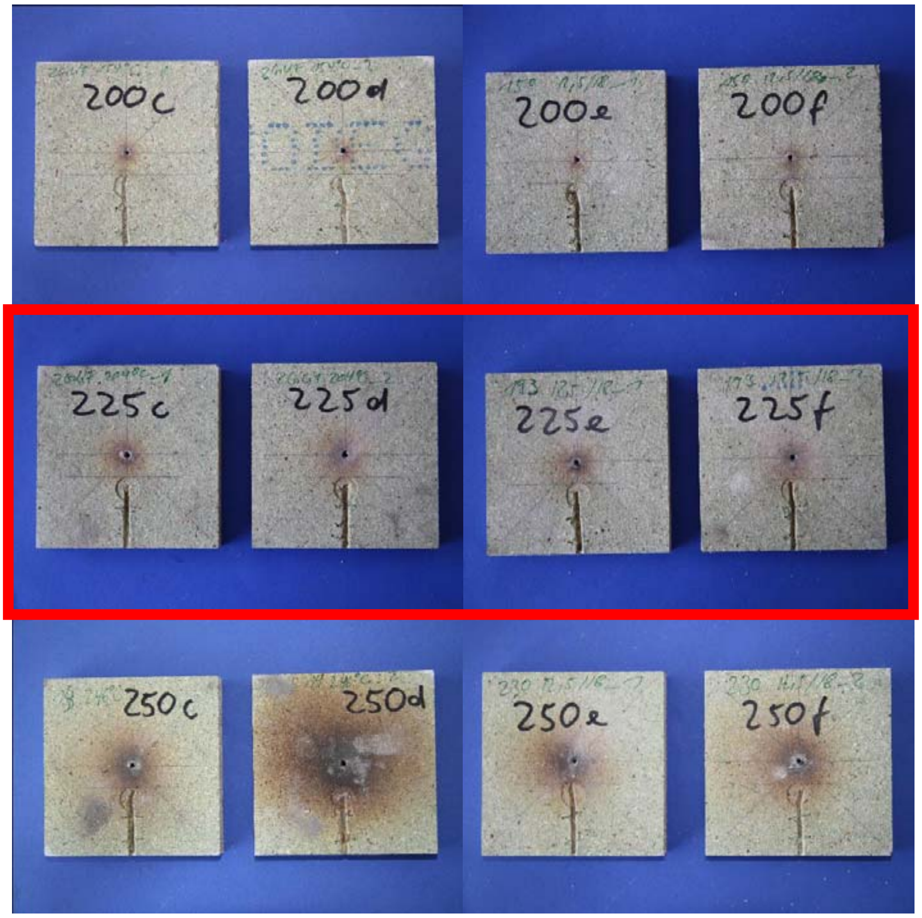

Fig. 2: Discolorations in the vicinity of the screws at different temperatures

The following statements regarding metal fixing devices only apply when these devices are used in combination with a fire-protection cladding which complies with the temperature criterion in the unaffected area and which exhibits no carbonization. Furthermore it must be ensured that the fixing devices are spaced apart such that the discoloration areas do not affect each other.

The investigations were carried out using the worst fixing device from the point of fire protection, namely, the screw. Wallboard staples, which are used more commonly in practice, have a slimmer shaft diameter and thus lower thermal conduction. They are therefore in the final analysis to be regarded as preferable. This means that the investigation results, keeping as they do on the safe side, will also apply to wallboard staples. A staple, which has two legs, is to be regarded here as a fixing device. Statements made here relate only to metal fixing devices with a shaft diameter of less than 4 mm, since larger diameters were not investigated.

Screw-extraction tests were carried out to see whether a carbonization spot is associated with permanent damage to the wood itself or whether only a discoloration occurs. The critical temperature turned out to be 225 °C, measured at a distance of 5 mm from the fixing device (Fig. 1). It is for this reason suggested that the discoloration pattern for 225 °C as shown in Fig. 2 be accepted as the maximum permitted discoloration in the vicinity of a fixing device. This opens up a considerable optimization potential for effective fire-protection cladding which can in future be dimensioned less thick.

3 Adhesive bonding

One possible way of reducing the thickness of the fire-protective cladding is to use adhesive bonding. If the gypsum boards are glued to the timber post-and-beam structure there will be no need for the pin-shaped metal fixing devices. Glued joints are however not suitable as a shear-resistant way of connecting gypsum boards on the timber post-and-beam structure of bracing components when exposed to fire. In the event of a fire the material becomes permeated by moisture so that the load-bearing capacity of the glued joints drops prematurely and the connection fails. The provision of a vapor barrier only shifts moisture-related failure to another plane and cannot prevent premature failure due to shear failure. In view of the current state of development any further investigation into bonding does not appear advisable for this particular application.

Gluing the outer layer of the fire-protection cladding onto the inner layer (Fig.3) does have potential. This joint is stressed solely by the gypsum board's own weight. Full-area gluing using gypsum-based bonding agent was a promising possibility. Use of an adhesive bond means that making a $K_2$60 cladding 2 x 15 mm thick is possible in principle (Fig.4). However, a final assessment, including the effects of temperature-related constraining forces and of cracking behavior, does call for fire tests at full scale.

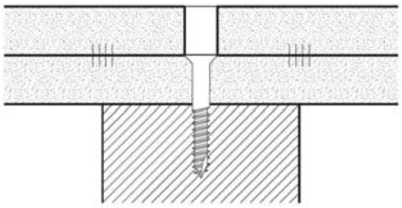

Fig.3: Gluing the second board layer onto the first and countersinking the fixing device

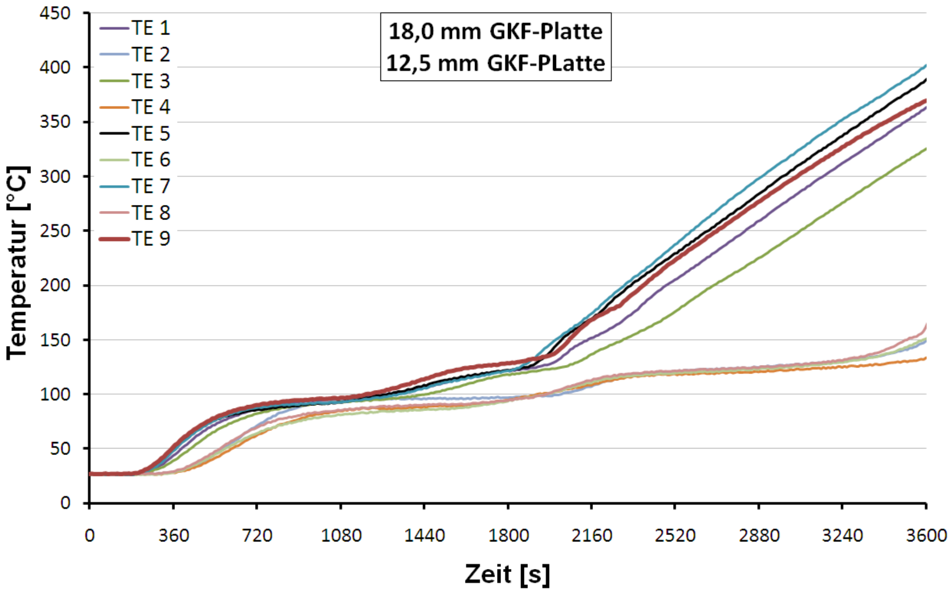

Fig.4: Temperature curves for 18 mm + 12.5 mm gypsum boards

Key:
Temperatur = Temperature
GKF-Platte = Gypsum board
Zeit = Time

4 Investigation of fire behavior in the case of bracket loads

By definition buildings consist only of a structural framework, partitions and encasing components. These elements are accordingly subject to the provisions of building regulations. A building must, however, be equipped with interior fittings corresponding to its type of utilization. This is where we find a central problem in medium-rise wooden buildings. The highly fire-retardant walls are encapsulated in a two-layer cladding of gypsum boards. Penetrations are not permitted unless specific design requirements are met. However, the application of bracket loads to these walls is not regulated. Classic bracket loads include, for example, kitchen cabinets in dwelling houses or shelves and filing cabinets in offices and administrative buildings. Experiments have revealed some good approaches in anchoring bracket loads to highly fire-retardant components by the provision of a steel plate or a flexible rail, and without impairing the protective effect of the fire-protection cladding. Passing large-diameter metal fixing devices through both layers of the fire-protection cladding and directly into the wood was to be avoided. This is possible if the screws fasten into a steel plate or a flexible rail. Another consequence of installing a steel plate inside the fire-protection cladding is that it reduces temperatures at the rear face of the cladding. This is to be attributed to water vapor permeation being impeded. From the results we can derive the following design rules for highly fire-retardant walls to which bracket loads are intended to be applied.

4.1 Attachment to the framing

Attaching bracket loads to the framing by means of screws which penetrate the fire-protective cladding is only permissible when the diameter of the screws is limited. The only type of screw permitted is the type tested for the attachment of fire-protective cladding in accordance with DIN EN 13501. Smaller dimensions are permissible.

Screws must be spaced at least 5 cm apart.

4.2 Attachment to the gypsum cladding (between studs)

Attachment of bracket loads in the area between framework studs is permissible under the following general conditions:

- Plastic dowels, which melt at an early stage in the event of a fire, must be used. The attachment points must not be closer than 5 cm to the combustible framework.
- The use of toggle fixings is permissible in conjunction with combustible furniture systems which in the event of a fire will drop off the wall after a relatively short exposure to fire (for example, conventional kitchen cabinets made of wooden panels up to 16 mm thick). The attachment points must not be closer than 10 cm to the combustible framework.
- If toggle fixings are used in conjunction with non-combustible furniture systems such as metal shelving or similar, the load must be limited. The load permitted for the structure in question should be determined.

For 2 x 18 mm gypsum wallboard panels a permitted tensile load of 300 N was determined (cf. Section 4).

4.3 Attachment to solid wood structures / wood-based panels

Bracket loads may not be applied to solid wood structures or wood-based panels through the fire-protective cladding unless wood screws are used which have been tested for suitability for use with fire-protective cladding. Smaller dimensions are permissible.

Screws must be spaced at least 5 cm apart.

The use of toggle fixings or the like in conjunction with wood-based panels is not permissible.

4.4 Special designs for bracket loads

On the basis of the present state of knowledge it is possible with the designs dealt with below to attach bracket loads safely even as regards fire-protection aspects.

Variants 1 and 2: Attachment of bracket loads to a flexible rail

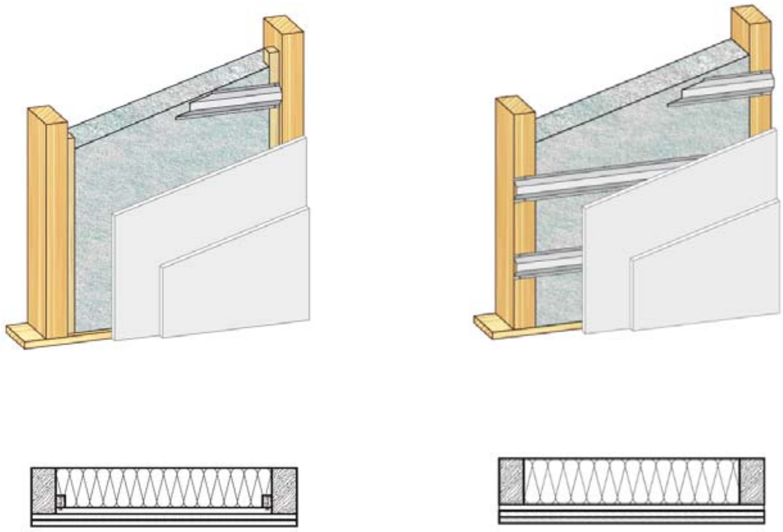

Fig. 5: Flexible rail flush with (left) or mounted onto the timber post-and-beam structure

During fire tests it was demonstrated that designs using flexible rails permit a thinner paneling structure. For a K60 classification, 2 x 15 mm gypsum wallboard panels will probably suffice. However, documented evidence of conformity has not yet been obtained as regards large-format fire tests as specified in DIN EN 14135. Attachment to the flexible rail using 8 mm screws permitted a load of 400 N.

Variants 3a and 3b: Steel plate (3a) or wood-based panels (3b) on the wooden framing.

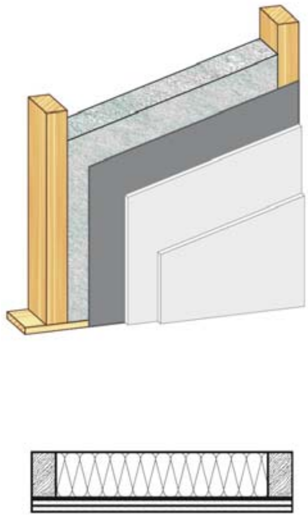

Fig. 6: Load-transferring layer on the wooden framing

In this design variant the sheet steel or wood-based panel serves as a load-distributing or bracing layer.

If a wood-based panel is used the comments made in Section 4.3 will apply. If a sheet steel panel is used it will probably be possible to use toggle fixings. Since no test data are available in this regard, no recommendations may be made. This design variant does not however have any potential for optimization of the fire-protective cladding. For commercial reasons this design cannot therefore be recommended for bearing bracket loads safely.

Variant 4: Sheet steel plate between the gypsum panels

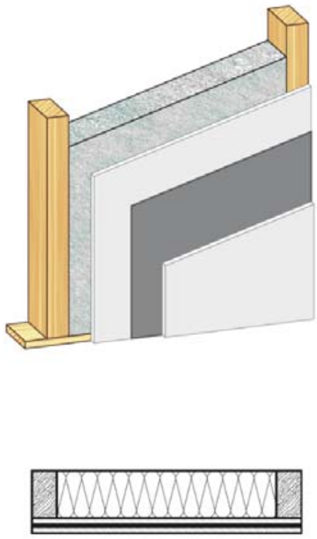

Fig. 7: Load-transferring layer between the gypsum panels

This variant is of interest from the commercial point of view since on the one hand it results in an optimized cladding and on the other hand permits a safe absorbance of bracket loads.

During fire testing it was possible to demonstrate that loading with a tensile load of 400 N is possible with a screw with a diameter of 8 mm. Dowels do not need to be used. Attachment can be effected by screwing in directly.

Variant 5: Pre-wall installation panel (if necessary using a flexible rail as well).

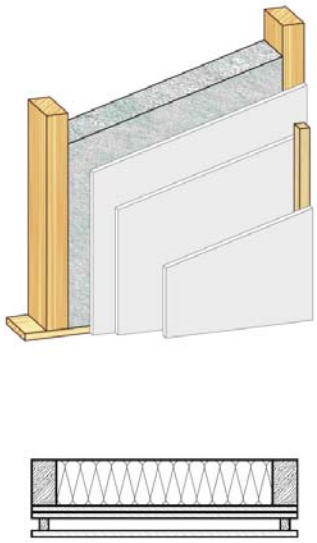

Fig. 8: Pre-wall installation panel

This variant is also of commercial interest since it can also accommodate the wiring or piping required for kitchen units, for example. The bracket loads are attached to the pre-wall panel, which does not form part of the actual fire-protective cladding.