Short report for the research project

Standardising the fire safety performance of timber frame elements using bio-based insulation materials

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Objectives and initial situation

Architects and engineers strive to build sustainable, energy, resource and cost efficient structures by using bio-based building material. The aim is to utilise the excellent environmental performance of these material within the construction sector. Therefore, an increasing amount of bio-based insulation and lining materials are currently used in timber frame constructions for walls and floors. Their technical and structural properties are the basis of an optimised design. To verify the fire safety requirements in respect to the fire resistance of such elements and constructions not only National and European technical approvals or classification reports, which are based on test results, but also the tabulated values/constructions of the German design standard DIN 4102-4 can be used. However, this standard is based on a conservative assumption and neglects the contribution of bio-based cavity insulation to the fire resistance of the whole element. All options currently available are time consuming, expensive and/or conservative and inhibit the use of bio-based insulation or lining materials.

To overcome this limitation and gap of knowledge and to reduce the time, cost and effort in proofing the fire safety for these constructions an improvement of the Component Additive Method towards bio-based building products is needed. The aim of this research project is to include bio-based insulation materials and linings in a standardised European calculation method for the fire resistance of timber frame elements, which allows both the assessment of the separation- and load-bearing function.

This enables the efficient application of these materials in buildings with requirements to fire resistance. An additional separate verification will not be necessary any more. Based on the standardised calculation method a high number of timber frame elements can be designed fulfilling the fire resistance requirements without further proofing and fire testing.

This will help designers, authorities and producers to overcome existing constraints and limitations. The project contributes to reduce constraints and to facilitate the application of bio-based insulation materials and linings in structural engineering. In addition this project aims to investigate the material specific behaviour of bio-based insulation under elevated temperatures, in order to wider the knowledge about the temperature induced degradation and to develop approaches to optimise these materials and constructions with bio-based insulation.

Realisation of the research project

With the compilation of the potential fields of application of bio-based insulation materials, the fire safety requirements for standard buildings and special purpose buildings were identified, in order to ensure the practical relevance of the future research results.

In a survey of the market relevant constructions and materials for practice, within the scope of the research project were identified. The focus was on the type of insulation materials, their thickness, the typical layup of elements and the structural design for corresponding timber frame elements.

Due to the wide variance of the potential bio-based insulation materials and types of constructions, this project focused on cellulose and wood fibre insulation, to cover the present market situation, see Figure 1.

Figure 1: compilation of the considered insulation materials (from left to right) – flexible wood fibre insulation, ,blown-in cellulose insulation, wood fibre board

Within a first experimental series, the behaviour of the aforementioned insulation materials were assessed under elevated temperatures up to 250 °C. Under focus was mainly the temperature dependent structural- and dimension stability of the insulation materials, because of the specific raw materials and additives used in production significant changes were to be expected already in this temperature range. In addition to the dimension stability also the mass loss rate under temperature exposure was assessed, in order to predict the shrinkage of the insulation material before flaming combustion. Based on small scale furnace fire tests several setups of timber frame elements were investigated, in order to assess the contribution of bio-based insulation materials to the fire resistance. All specimen were exposed to standard fire exposure, in accordance with EN 1363. This approach allowed the investigation of material and construction specific aspects with respect to the influences of the type of insulation, the production technique of insulation, the thickness, the interaction of layers at exposed and unexposed side, fixation methods and influence resulting from the orientation as wall- or floor element. The tests were conducted in a furnace, which allowed the fire exposure for a wall and a floor element at the same time in one test. Each wall and floor element comprised two 625 mm wide insulated cavities, see Figure 2. The fire expose surface of each element had a minimal size of 1,3 m². To assess the protection capacity of each layer thermocouples were applied to record the temperatures in the specimen behind each layer. Furthermore, the specimen were visually observed from the outside and through a window within the furnace wall during the tests, to document shrinkage effects of the insulation and the falling-off of linings.

a) b) c)

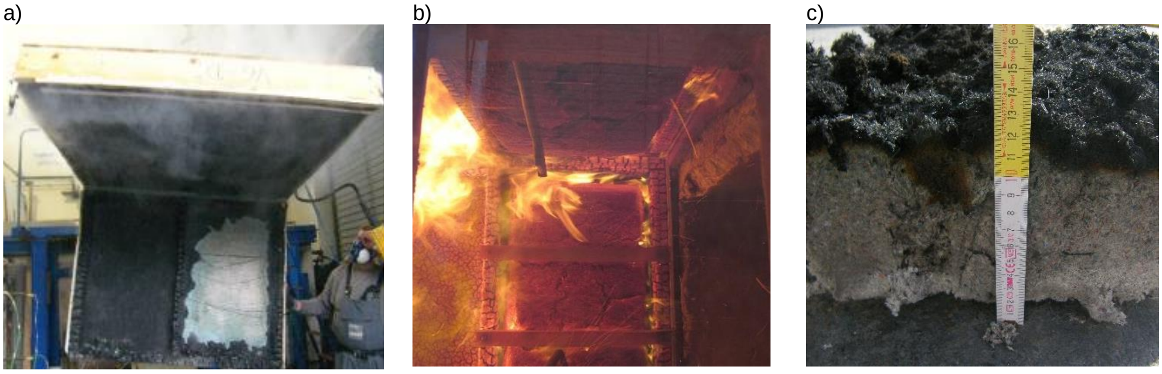


Figure 2: small scale tests with wall and floor elements; a) L-shaped specimen during removing from the furnace after fire test, b) view at the fire exposed specimen, c) cellulose insulation after fire test

Beside the investigations oft the separation function of timber frame elements within the small scale fire tests the positive influence of the cavity insulation on the timber members (studs/beams) was investigated too. Thus, an assessment of the magnitude of fire exposure (one / three sided) and resulting charring to the load-bearing structure became possible by recording and documenting the recession of the insulation away from the timber element, visually and by thermocouples at the timber studs and beams, see Figure 3.

a) b) c)

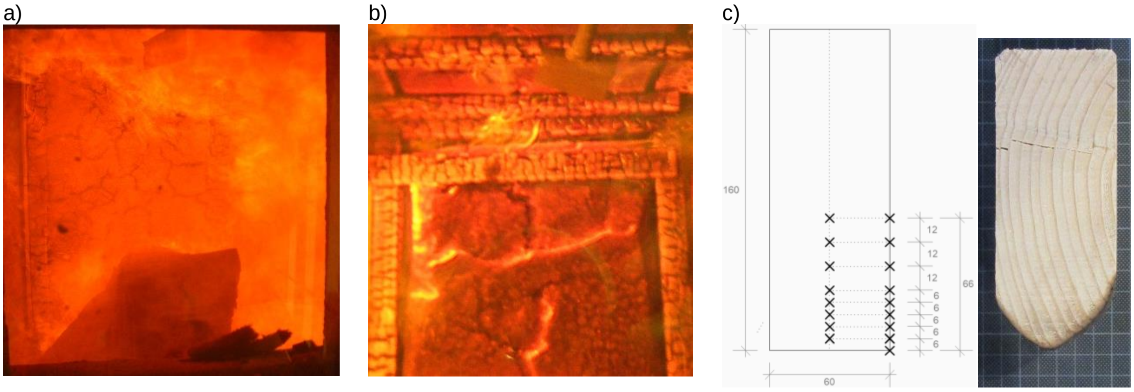


Figure 3: small scale tests with wall and floor elements; a) induces falling-off of protective lining, b) recession of insulation at a timber stud, c) measurement points for recording the recession speed and cross-section after fire test

In addition the remaining cross section of the timber frame elements after fire exposure were registered. Within the experimental assessment, also the influences resulting from the specimen orientation (wall / floor) and the pre-heating of insulation in the time before the protective lining failed were considered. In this context a method to induce a controlled complete falling-off of protective linings at a specific time was developed.

In a further step of the research project temperature dependent materials properties for thermal conductivity (λ) specific heat (c_p) and density (ρ) were determined, as basis for further numerical parameter studies. Beside the hot-disc-method also the hot-plate method and thermal gravimetric analysis (TGA) were used. In addition, these material properties were also derived from a numerical algorithm using in depth temperature measurements inside the specimens from fire tests. These different approaches finally allowed a comparison of the material properties and an assessment about the influence of the used method to the gained results. An already at the chair for timber structures and building construction established numerical approach based on the transient heat transfer (Fourier law) in combination with the previously determined material properties for bio-based insulation materials was used in further extensive numerical studies, in order to investigate the influence of individual parameters. In particular, the thickness- and density influence, the position within the structural layup and the influence of fire rate linings, with falling of time greater than the start of charring time, on the temperature distribution within the construction were assessed.

The conducted fire tests and numerical simulations were basis for the determination of empirical equations, which allow the assessment of the bio-based insulated timber frame analytical in the Component Additive Method – (CAM).

To the proof the applicability of the derived equations, their validity was compared with full scale fire test results. To this, a database, collected at the chair of timber structures and building construction with 133 fire test results for timber frame elements with bio-based insulation materials was used. This database allowed a validation and optimisation of the analtical equations. In this context is became obvious that small scale fire tests are an appropriate mean to assess the heat transfer under fire exposure. However, effects like the falling-off of linings or cavity insulation can finally assessed in full scale fire tests.

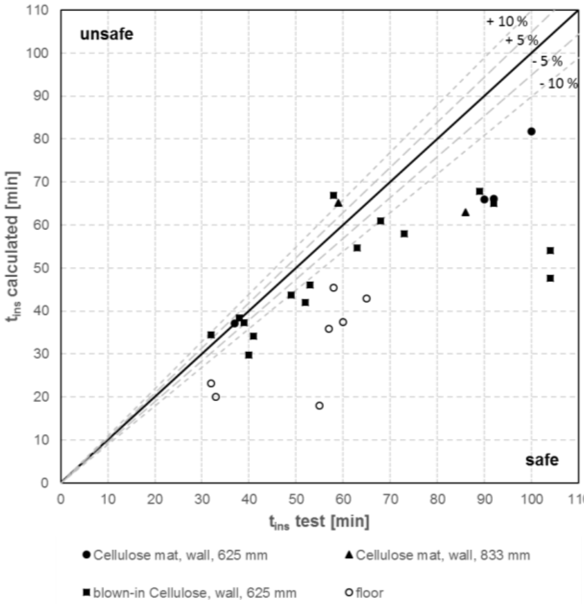
Conclusion

The conducted market studies, experimental testing and the numerical and analytical assessment of this project aimed to investigate and standardise the fire safety performance of timber frame elements with bio-based insulation materials. Main objective was the integration of this knowledge into a standardised assessment method, in order to reduce the obstacles in using bio-based insulation materials. Furthermore, the research results provided new findings about the material properties and also method to determine these values and system specific influencing factors for timber frame elements. At the same time the research project provides new knowledge about the behaviour of cellulose and wood fibre insulation at elevated temperatures before flaming combustion. The research results have shown, that product specific additives in the insulation materials can influence the dimension stability in a negative way without leading to a shrinkage of the material already in a temperature range under 250 °C. Reaching higher temperatures resulting in flaming combustion conditions, the aspect of shrinkage becomes more dominant – especially for wood fibre insulation products, resulting in an opening of joints and recession of cavity insulation away from timber members. For cellulose fibre insulation the temperature dependent shrinking was less dominant. In comparison to high temperature stabile mineral wool products (melting point > 1000 °C) this aspect can influence significant the contribution of bio-based insulation materials to the fire resistance of timber frame elements. These temperature induced shrinking process and loss of dimension stability can lead not only to an earl opening of joints or falling-off of part of the insulation materials with respect to the assessment of the separation function of timber frame elements, but also will influence the load bearing capacity of timber studs and beams when not sidewise protected from insulation material anymore.

To investigate specific materials and system behaviour new assessment techniques and set-ups were established, allowing the time specific falling-off of protective layers and the evaluation of the protective capacity of the insulation materials in the protection and post protection phase of the lining. Also the continuous assessment of the recession speed based on embedded thermocouples was an innovation in the experimental investigations.

Based on the experimental and numerical investigations analytical equations to be used in the Component Additive Method for cellulose-, wood fibre and insulating wood fibre boards were developed, in order to allow the assessment of the separation function in case of fire up to 90 minutes. Figure 4 a) exemplarily shows a comparison between the results from the improved CAM and full scale fire tests results for timber frame elements with cellulose fibre insulation. It must pointed out, that for blown-in insulation materials and materials with a high shrinkage behaviour an increased risk of a falling-off of the insulation exists, and must considered by structural methods. Based on the full scale tests results, the k_{fall} factor was introduced in the CAM, limiting the protection capacity of such insulation materials beside the protection capacity derived from heat transfer.

a)



b)

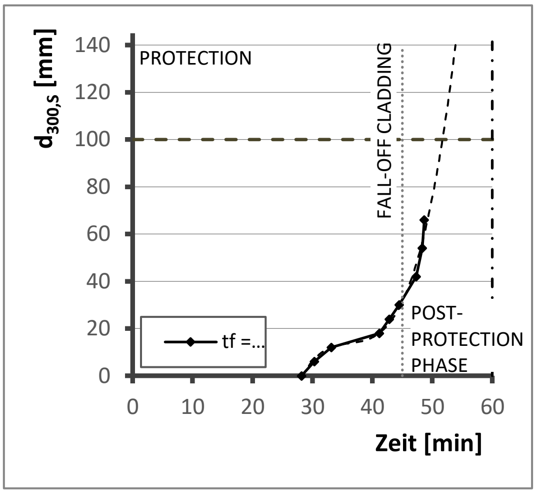


Figure 4:

a) comparison of the insulation capacity t_{ins} for wall and floor constructions with cellulose insulation in tests and calculation method

b) determination of the protection level for wood fibre insulation

With regard to the assessment of the load-bearing capacity the insulation materials examined were assessed on the basis of the protection level (PL) concept. This concepts allows the assessment of the protective capacity of the insulation on loadbearing timber members, before and after falling-off of the protective linings, see Figure 4 b). For the assessed cellulose insulation a protection level – PL 1 and for the flexible wood fibre a protection level – PL 2 was reached. Again, it must be pointed out, that an earl falling-off will lead to a worse classification.

Finally, it remains to be noted that the CAM should be extended in future with respect to consider explicit the falling-off criteria as further limiting factor for insulation materials.

Furthermore, research is needed with regard to the influence of external plaster layers at ETICS, the influence of cavity widths larger 625 mm, the influence between blown-in and mat type insulation and the efficient structural fixation measures for cavity insulation. Aforementioned points are under further investigation by the authors.

With the here presented results the assessment of the positive influence of bio-based insulation materials to the fire resistance of timber frame elements becomes standardised possible. This was not possible until now based on the approaches of DIN 4102-4. The derived results and analytical approaches for bio-based insulation materials will be made available to the standardisation committee within the current revision of EN 1995-1-2, to allow for further standardisation and application of timber constructions with bio-based insulation.

Facts

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