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IMPROVEMENT OF THE REACTION TO FIRE PERFORMANCE OF CELLULAR WOOD MATERIAL

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Abstract:
Cellular wood material is new product in global market and its performance in fire fundamentally is not known. The reaction to fire performance of cellular wood material and its improvement methods is presented in this paper. The reaction to fire performance of cellular wood material was valuated. This paper is focused on methods on the improvement of reaction to fire performance of this material. Several fire protection systems were developed with chemical and mechanical fire protection to improve fire performance of cellular wood material. Two different scale fire tests were used to evaluate reaction to fire performance of developed prototypes. Six different chemical fire protection applications were tested in cone calorimeter test and five different cellular wood material prototypes were tested in single burning item. Fire growth rate and total heat release of burning material was analysed as well as heat release dynamics during the test. The fire performance of cellular wood material could be increased by tested fire protection systems.

Key words: *reaction to fire; cellular wood material; fire retardants.*

INTRODUCTION

Light weight building systems are actual topic in building industry now. It gives possibility to decrease building costs and to improve energy efficiency of building. Cross-laminated timber (CLT) product is well known product and it has stable market in building industry. Lot of ideas of light weight panels for building industry has been developed, but only some of them has been realised in life. Some of light weight panel ideas were described by Skuratov (2010). In October of 2010 the manufacturing of the cellular wood material DendroLight® started in Latvia and this product now is available in market. The product was invented by Johann Berger (Berger 2006) and first industrial plant was built in Latvia.

The technology of cellular wood material offers to decrease the apparent density of material. If the density of coniferous wood is 500kg·m^{-3} apparent density of the cellular wood material will be equal only to 270 – 320kg·m^{-3} (Skuratov 2010). About 200kg of clean and dry wood saw dust can be used for other purposes from each cubic meter of raw material. Hitherto the internal layer of cell panel of cellular wood material type has been produced mainly from softwoods like Norway spruce (*Picea abies* L.) or Scots pine (*Pinus sylvestris* L.) covered with plywood, solid wood, particleboard or other material (Lejavs *et al.* 2011). Light weight birch plywood structural panels with increased strength properties were developed by Zudrags (2010) in his PhD thesis.

The reaction to fire and fire resistance properties of wood materials are influenced by large amount of factors. Investigation of them was done by Buksans (2010) in PdD thesis. Fire retardant treatment of wood is one of the most discussed topics between fire scientists related to wood materials fire safety.

Solid timber constructions are well known in fire science with predictable and good performance in fire. A cellular wood material is completely different wood products due its structure. Fire retardant treatment technology of cellular material also differs from solid timber treatment. There is a lot of questions without answers regarding cellular material performance in fire.

OBJECTIVES

As cellular wood material is a new product in the market, the knowledge about product physical and chemical performance is missing. This study brings new knowledge about cellular wood material fire performance and methods of the reaction to fire and fire resistance improvement. New product prototype for application in fire resistant doors was developed in this research work.

METHOD, MATERIALS AND EQUIPMENT

Material

Cellular wood material can be produced from different relatively low density wood species. Pine (Pinus Sylvestris L.) wood was used for production of cellular wood material. Production process of cellular wood material starts from four side calibration of sawn timber and grooving with 3mm groves from both sides of the board (see Fig. 1a). Then these grooved boards are glued together in cross-laminated timber (see Fig. 1b). These panels can be used in building systems and they are called as parallel orientation cellular wood material panels. Parallel orientation cellular wood panels can be cut in lamella by bandsaw and glued together. This is called perpendicular orientation cellular wood material panel (see Fig. 1c). Perpendicular orientation cellular wood material has considerable dimension stability, and moisture changes do not affect dimensional changes.


a b c

Fig. 1
Production technology of cellular wood material
a - grooved board; b - cross-laminated timber; c - perpendicularly cut and glued panel.

Preparation of specimens

To achieve the objectives of the research, different material combinations and variations were prepared for reaction to fire testing. Six different fire retardant treatment systems were prepared for small scale testing in cone calorimeter and identification of specimens are shown in Table 1. Five different reactions to fire improvement methods used in large scale testing and results were compared with solid wood test results.

Table 1

Identification of product variations used in fire tests

Marking	Description	Test standard	Number of specimens
D-cont	Cellular wood material in perpendicular orientation without any treatment	ISO 5660-1	5
D+A1	Cellular wood material treatment with fire retardant TENTS, treatment done by immersion method with total consumption $95kg \cdot m^{-3}$	ISO 5660-1	5
D+A2	Cellular wood material treatment with fire retardant FAP, treatment done by immersion method with total consumption $76kg \cdot m^{-3}$	ISO 5660-1	5
D+A3	Cellular wood material treatment with fire retardant Antipirens RS, treatment done by immersion method with total consumption $85kg \cdot m^{-3}$	ISO 5660-1	5
D+A4	Cellular wood material treatment with fire retardant Unitherm AWR, treatment done by coating method with total consumption $1000g \cdot m^{-2}$	ISO 5660-1	5
D+A5	Cellular wood material cells filled with special fire retardant mastic prepared on basis of Unitherm AWR	ISO 5660-1	5
D+A6	Cellular wood material treatment with fire retardant MP FR, treatment done by immersion method with total consumption $80kg \cdot m^{-3}$	ISO 5660-1	5
D+A6vent	Cellular wood material treatment with fire retardant MP FR, treatment done by immersion method with total consumption $80kg \cdot m^{-3}$, ventilated construction allowing natural convection occur	ISO 5660-1	5
Spruce	Solid spruce *Picea abies* L. wood as reference	EN 13823	5
D-MDF4	Cellular wood material with 4mm thick medium density fibre board facing	EN 13823	1
D-Mg	Cellular wood material with 6mm thick magnesite board facing	EN 13823	1
D-Mortar	Cellular wood material with special mortar covering	EN 13823	1
D-FR	Cellular wood material with special fire retardant mastic faced with 1.6mm high pressure laminate (HPL)	EN 13823	1
D-Pine	Cellular wood material with 7mm thick Pine (*Pinus Sylvestris* L.) wood facing	EN 13823	1

Several prototypes of cellular wood material were developed, and more detailed information about these ideas cannot be covered by this article. 3L – three layer type panels with increased reaction to fire and fire resistance were developed in research. Ventilated cell problem was solved by special ecological material base mastic and improved reaction to fire performance achieved by high pressure laminate facing (see Fig. 2). Thermo reactive glue should be used in all cases when we talk about improved fire performance of composite wood material.

Fig. 2

Cellular wood panel with improved fire resistance properties.

Test methods and equipment

Reaction to fire testing was done according two different test methods. Small scale tests were done on cone calorimeter according standard ISO 5660-1:2002. Five specimens with dimensions 100x100mm were prepared for each variation of product. The thickness of all tested specimens was 50mm.

Large scale reaction to fire testing was done in single burning item (SBI) equipment according standard EN 13823:2010. The specimen consists of two wings connected together in 90º angle. The dimensions of specimens were 500x1500mm for short wing and 1000x1500mm for long wing. As these tests were used as indicative criteria for predicting potential reaction to fire performance of prototypes, only one test from each product variation was performed.

All specimens were conditioned in 50±5% relative humidity and 23±1ºC temperature environment until constant mass of the specimen reached. Conditioning was done in accordance with standard EN 13238:2010 requirements.

Special specimen holder with open bottom part was made to evaluate natural convection influence on burning process of cellular wood material. Air channel dimensions were the same as specimen size – 100x100mm.

RESULTS

Small scale reaction to fire tests

The main results from reaction to fire tests in cone calorimeter are peek heat release rate of burning specimen and total heat release. These two factors can describe potential fire performance of product in large scale testing, which is basis of European classification system according standard EN 13501-1:2010. Different material variations are compared in Figures 3 and 4. All tests were done in horizontal specimen orientation at heat flux 50kW·m^{-2} radiation. All fire retardants used in experiments decreased peek heat release rate at least twice (see Fig. 3).

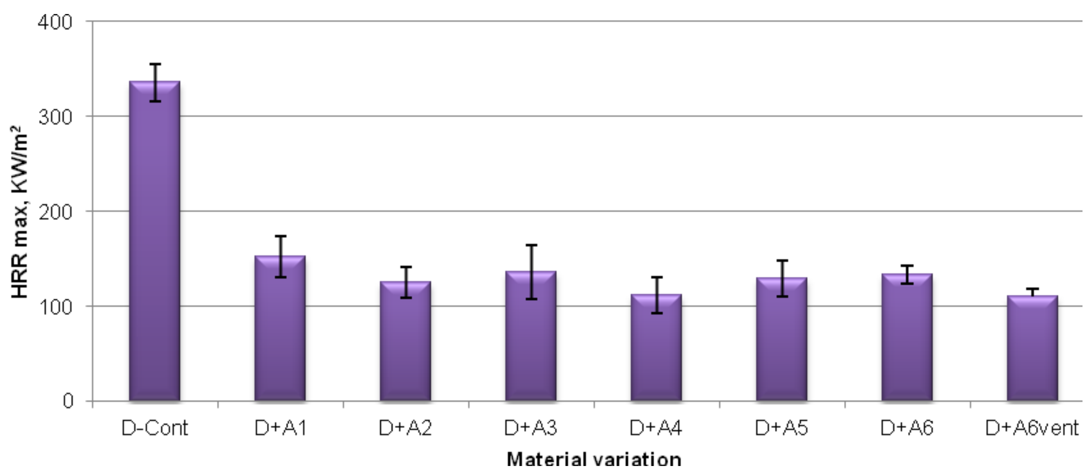

Fig. 3
Comparison of peak heat release rate of different fire retardant treatment systems on cellular wood material.

Difference between fire retardant efficiency on peek heat release rate does not exceed 30%. Larger differences can be observed in total heat release rate values THR 0-300s and THR 0-600s (see Fig. 4). The highest efficiency was achieved for product variation D+A5. Blocking of open cell structure is key factor to decrease heat release of burning cellular material. Obtained values of the reaction to fire performance can be used for prediction of test results in large scale test. All product variations test results didn't comply with Euroclass B. Euroclass C or D can be achieved by tested fire retardant treatment systems in dependence from product variation.

The analysis of heat release rate dynamics of different product variations shows significant findings in burning process of cellular wood material. Figure 5 shows typical fire development dynamic of untreated and unventilated cellular wood material in perpendicular orientation. All wood materials have typical high peek heat release rate. Char formation on the exposed surface of the specimen works as insulating material and prevents wood heating up, drying and pyrolysis. The burning process becomes stable due to char formation.

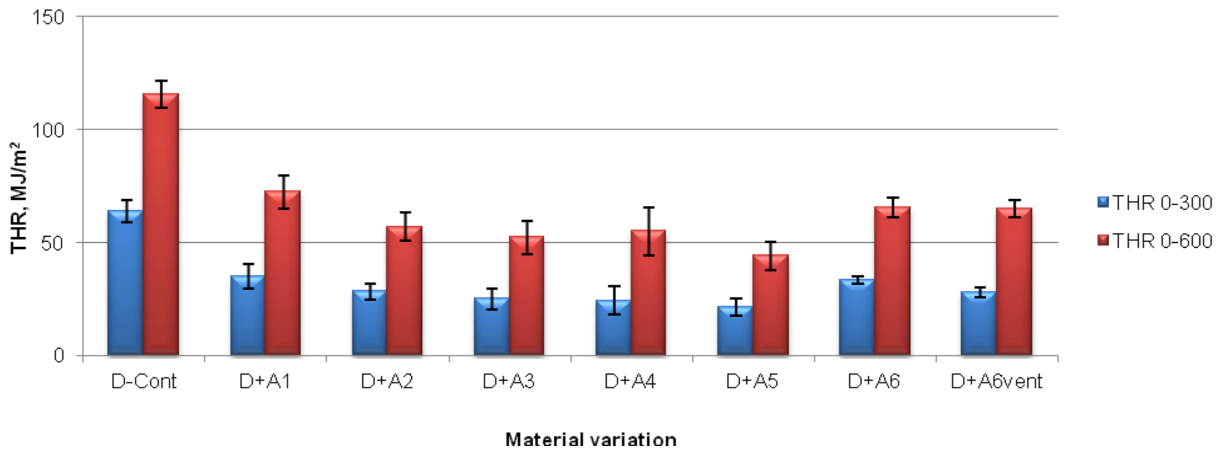

Fig. 4
Comparison of total heat release in 300s and 600s of different fire retardant treatment systems on cellular wood material.

The situation is different with fire retardant treated wood. Fire retardants usually prevent from high peak heat release rate (see Fig. 6). Fire retardants also help to keep thicker char layer and that means slower combustion process of wood. Fire retardants prevent wood product from fast fire development, but it is still combustible material. Efficiency of fire retardants on cellular wood material is higher than on solid wood, because cells allow complete impregnation of wood.

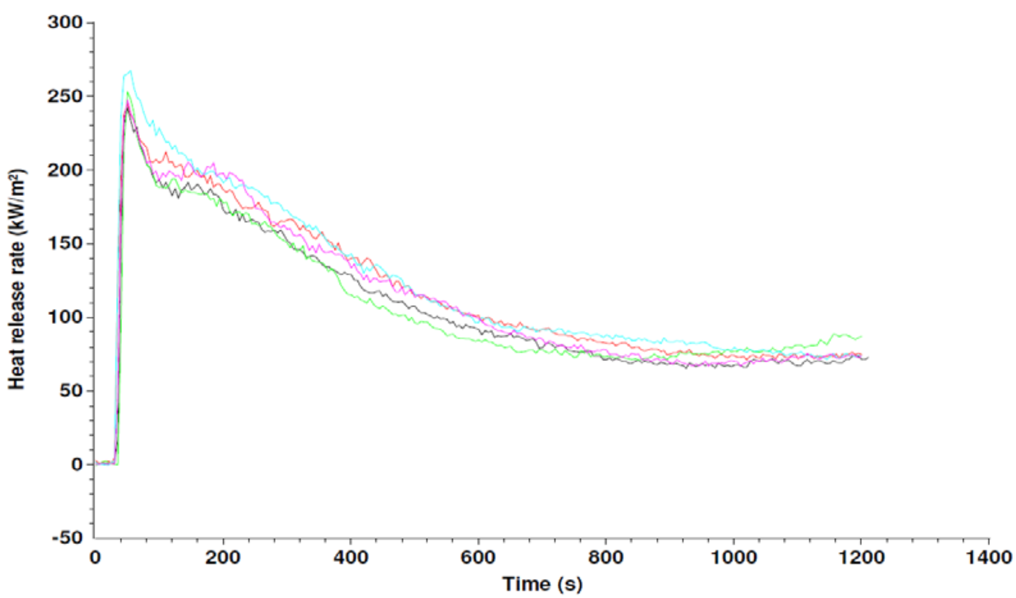

Fig. 5
Heat release rate dynamics of untreated cellular wood material in perpendicular orientation.

The problem of ventilated cells and natural convection during fire was mentioned in introduction and experimental results show that fire retardants do not solve this problem. The beginning of test is the same as for specimens with unventilated construction, but the following increase of heat release rate was observed (see

Fig.7). However there is no big difference in the beginning of test, further fire development can be critical in real fire. Natural convection in real fires supplies fuel with oxygen. So fire prevention plan should consist of blocking fresh air supply to the materials.

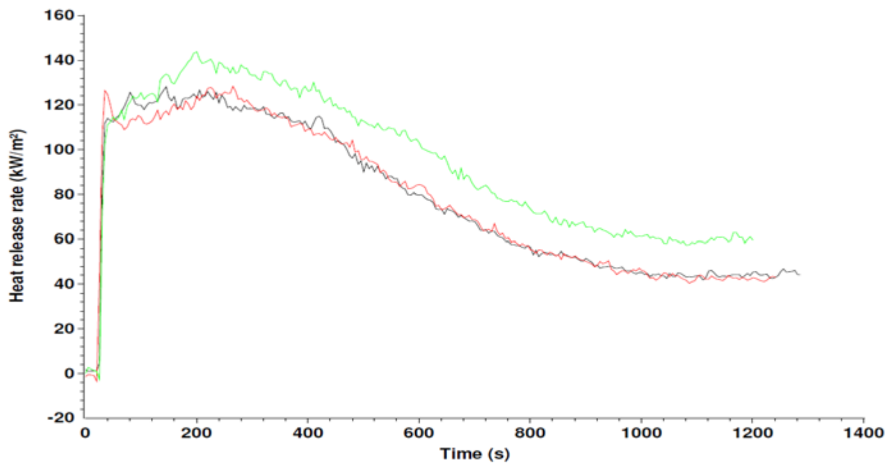

Fig. 6
Heat release rate dynamics of fire retardant treated (A-6) cellular wood material in perpendicular orientation.

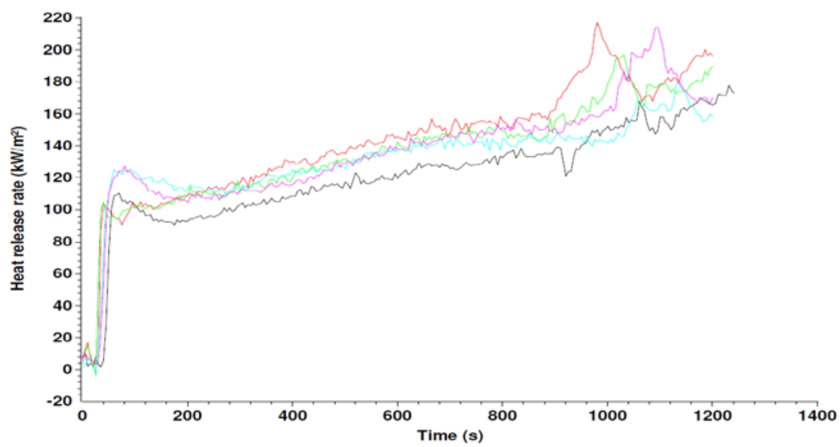

Fig. 7
Heat release rate dynamics of fire retardant (A-6) treated cellular wood material in perpendicular orientation with enabled cell ventilation.

Large scale reaction to fire tests

The scale of fire test plays a big role in fire science. It is very difficult to make a good fire development model because there are too many influencing factors in real fire and it is not possible to take everything into consideration. Reaction to fire classification system is introduced in Europe to take into consideration risks from building materials. Single burning item is one of the most important test methods in classification system and it can be interpreted as large scale testing.

Different product variations were tested in single burning item and the main results - fire growth rate and total heat release in 600s were used to describe test results (see Fig. 8 and Fig. 9). This test method shows that the best protection of cellular wood material is facing it with inorganic materials – magnesite board and mortar. The cement fiber board or gypsum plasterboard can be used instead. This fire protection model works very well if inorganic content facing does not collapse, neither split and keep rigid in fire.

Fire protection model by blocking fresh air supply to exposed surface, which is realized in specimen D-Pine, does not work so well, but it is completely nature friendly solution if reaction to fire class is not required higher as D. Perpendicular orientation cellular wood material without any protection, cannot pass D Euroclass criteria. A very good result was obtained from test of cellular wood panel system D-FR. It shows increased reaction to fire performance due to HPL facing and increased fire resistance due to special fire retardant mastic blocking fire penetration in panel. This prototype can be used in fire resistant door construction. One significant advantage of cellular wood material is dimensional stability of panel. It does not change geometry till end of the test, which is critical for fire door integrity.

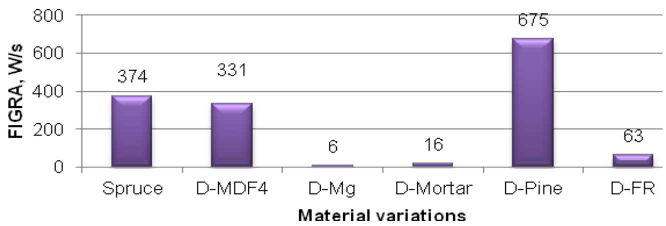

Fig. 8
Fire growth rate index (FIGRA) of different material variations.

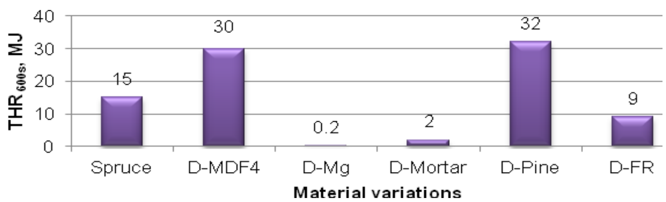

Fig. 9
Total heat release in 600s (THR600s) of different material variations.

Fire development dynamics analysis was done for each product variation and most important finding are shown in Fig. 10 and 11. Cellular wood material panel faced with 4mm thick MDF board shows fast fire growth and increase up to 80kW power. Then formation of char layer slowly promotes the decrease of heat release rate and after 10min from flame exposure moment specimen burns with constant heat release rate.

Completely different situation observed with magnesite facing covered cellular wood material. First heat release rate from wood material was observed only after 10min from flame exposure moment (see Fig. 10). This time was needed for pyrolysis process in wood behind magnesite board. Small flame development was observed on the surface due to cracks in magnesite board which started lose rigidity. There was no significant flame development till end of the test. This system ensures reaction to fire classification of product in B-s1-d0 Euroclass.

Very good results were achieved also with special fire retardant panel system D-FR. There was no peek heat release rate at the beginning of test and constant slow burning rate proceeded after 5min from flame exposure moment (see Fig. 11). Observations from test results show, that HPL facing thickness should be increased to achieve B-s1-d0 reaction to fire Euroclass criteria. Further work will be done in development of this prototype.

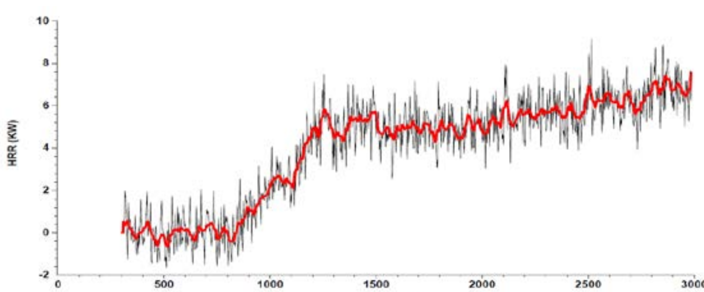

Fig. 10
Heat release rate dynamics of cellular wood material with 6 mm thickness magnesite board facing.

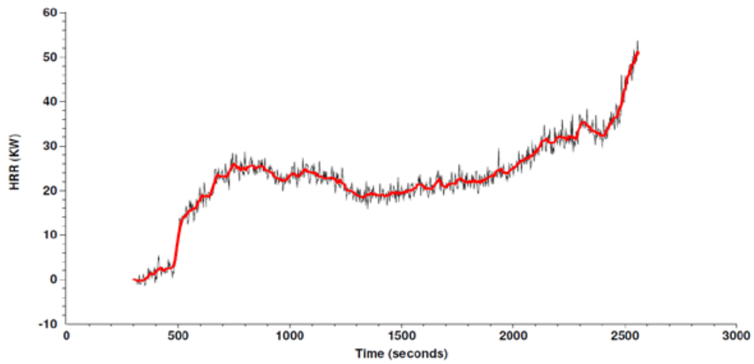

Fig. 11

Heat release rate dynamics of cellular wood material with fire retardant filler system and HPL facing.

CONCLUSIONS

There is good oxygen supply in cellular wood material due to structure, which is the reason of much worse performance in fire as solid wood materials. The first step to improve fire safety of cellular wood material is to prevent oxygen supply to cells. It can be done by covering with different facing materials.

The most effective method to improve reaction to fire and fire resistance properties is to cover cellular wood material with inorganic or high fire performance facing.

Fire retardant treatment with different type classic fire retardants significantly improves reaction to fire performance of cellular wood due to high consumption – about 100kg·m^{-3}. Reaction to fire classification criteria for B Euroclass is hardly reachable due to high heat release in the first 10min.

It is possible to develop new composite materials with good fire performance on basis of cellular wood material. The main advantage of this system is dimensional stability of product, which is very important factor for fire resistance.

ACKNOWLEDGEMENT

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