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REACTION OF DOOR CONSTRUCTIONS MADE OF CELLULAR WOOD MATERIAL TO FIRE

Cellular wood materials (hereinafter CWM) better known as Dendrolight® with their physical and mechanical properties are suitable for production of construction elements. A significant cost reduction, therefore, in transportation and mounting of the finished goods, as well as new and innovative modes of application based on the unique structure and lightness of the material, can all be achieved by developing the necessary technological and functional solutions. One of the possible building construction solutions are doors, including fire-resistant doors. This can be achieved by developing composites made of CWM and other materials that would meet the requirements set by building standards in terms of reaction to fire performance, fire resistance, and acoustics and developing CWM interconnection and fitting fastener solutions. The unique cellular structure ensures not only a reduced mass, but also a considerably better form stability under changing relative air humidity and temperature compared to materials used previously. During the research, initial tests were made to improve the reaction to fire properties of CWM by gluing it with some other materials. The results of the research showed that by gluing a CWM reference sample with 7 mm thick pine solid wood (longitudinal fiber direction) the charring and burn-through rates are the lowest compared to the other materials investigated. By reaction to fire performance specification, CWM with 7 mm thick pine solid wood, 4 mm thick MDF, or 6 mm thick MDF, gluing could be graded as class D in reaction to the fire classification system. The charring rate allows predictions of the potential fire resistance limit of door elements to be made. Assuming that the weakest spot in the construction is precisely the door elements, and of the materials tested, a 6 mm thick MDF or 6 mm thick magnesite panel was applied to both sides, CWM could be used to achieve EI 30 minutes fire resistance class limits.

Keywords: cellular wood material, reaction to fire, fire resistance, door elements

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Introduction

Wood is a suitable raw material for various products due to its high specific strength, as well as equally high tensile and compressive strength [Porteous and Kermani 2007]. Availability of high quality wood resources has always been limited, therefore, other kind of wood materials are being produced, including wood based panels produced from lower quality wood, obtaining products with high properties and a wide range of applications as a result of it.

Nowadays, there is a trend to produce lower density materials, thus reducing the production, transportation, and utilization costs. There are extruded particle boards, honeycomb and 3D boards, as well as other innovative materials. Cellular wood material or Dendrolight® is an innovation as well, made of low quality pine, solid wood sawn boards.

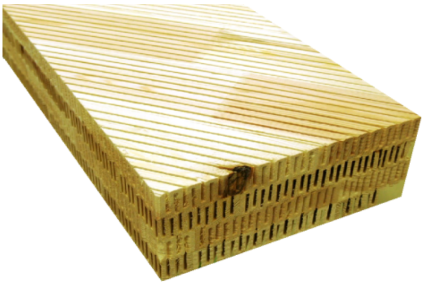
The reaction to fire performance specifications of construction products is one of the most important factors, and it must be stated when selling a construction product in the market [Östman and Mikkola 2004]. It is important to understand the characteristics of construction products under service class conditions in order to ensure the fire safety of a building at a certain level. The way to increase the fire safety of wooden construction materials is to understand their burning processes. CWM is not a typical wood product from the point of view of burning, however, it`s basic structure is solid wood, therefore, the learning process can be started with a wood burning process analysis. In general, the CWM burning process follows a similar principle, except for pyrolytic gas distribution directions. Research conducted by Rezka and Torero [2006] also reflects the course of wood pyrolysis and change of temperature in various wood layers, moreover, the impact of external heat release rate on the wood burning process are described as well. Of course, under fire conditions, construction products are exposed to different heat release rates, and the burning process may follow different scenarios.

The main wood construction fire resistance indicator, for wood materials is the charring rate and it has been researched by several authors. The results obtained vary within a wide range, from 0.5 to 2 $mm \cdot min^{-1}$ and it can be explained with different factors of influence. All the research has been conducted under high intensity heat release rate conditions, from 35 to 100 $kW \cdot m^{-2}$. The wood burning theory shows that the main factor in the wood burning process, is heating the wood until it reaches the temperature of pyrolysis [Schaffer 1967; White 2000; Hakkarainen et al. 2005; Hietaniemi 2005; Hugi et al. 2007].

Urbas and Parker [1993] have conducted research measuring the temperature of wood exposed to different levels of heat release rate. Data obtained demonstrated that the wood surface temperature was 600°C when exposed to the lowest intensity heat release rate, while a temperature of 800°C was observed when raising the heat release rate to 35, 65 and 80 $kW \cdot m^{-2}$, which indicated that the wood surface temperature does not increase if the heat release rate is raised above a certain critical value.

Under previously conducted research, CWM demonstrated different reactions to fire performance properties depending on the orientation direction of the product. Reaction to fire properties in perpendicular orientation of cells figure 1., were far poorer that in the parallel direction. This phenomenon can be explained by access to additional oxygen in the burning area and increased surface area involved in the burning process.

1



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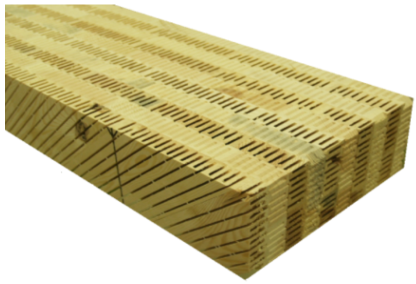

Fig. 1. CWM direction: 1 – parallel; 2 – perpendicular

In a parallel orientation, CWM can be classified as D-s2-d0 reaction to fire performance class, regardless of the fact that reaction to fire performance indicators – fire growth rate index (FIGRA) and total heat release (THR_{600s}) – were twice as high than those of at least 25 mm thick solid wood boards [Buksans et al., 2013; 2015]. Usually, CWM is used as the interlayer for composite panels. Wood cellular interlayer can be overlaid using different wood or wood composite materials, such as solid wood, plywood, MDF, as well as inorganic boards. This combination allows the fire safety properties of the product to be fully altered. Cellular wood material as an interlayer gives not only dimensional stability when wood moisture content changes, but also stability when exposed to fire.

So far, only a limited number of researches have been conducted on the properties of wood material made using the new, non-traditional technologies. It appears that cellular wood material may be used in construction, including manufacturing doors. Until now, material has been positioned as furniture and joinery production material and has lived up to the expectations. Whether the material can be used in the production of fire resistant doors remains an open question. The aim of this research is to conduct the initial study and find out whether this material can be used in the manufacturing of fire resistant door leaves and to predict the burning process of the investigated constructions.

Materials and methods

The determination of the reaction to fire performance properties of various constructive solutions for cellular wood material door leaves, has been conducted in accordance with the method described in the LVS EN 13823:2015 standard. The research intends to identify both the reaction to fire performance and the potential fire resistance of door panels. Test methods according to standard LVS EN 13823:2015 does not give the true fire resistance because this fire source does not follow the parametric temperature curve like in fire resistance tests. Another important point which is not covered by this research is the performance of joints, which play a very significant role in the fire resistance testing of door constructions. The methodology of the research work done, allows the comparison of different door leaf construction performance under the same fire exposure and predicting panel potential performance in fire resistance tests if joints are not taken into account. The charring rate of the panels was calculated from burn-through of construction.

For preparation of the middle layer with perpendicular direction, figure 1, of wood cellular material *Dendrolight*® pine wood (*Pinus sylvestris* L.) low quality sawn materials from the Baltic sea region with an average density of 530 kg·m^{-3} were used. After, the boards were grooved from both sides as production predicts [Iejavs and Spulle 2013], the average density of CWM was 327 kg·m^{-3}. MDF with an average density of 635 kg·m^{-3} for cladding was used. There is derogation from the method related to testing time which has been prolonged until the registration of sample's burn-out time. Description, labelling and numbers of the samples are given in table 1.

Table 1. Sample specification

No.	Name and composite combination	Material and sample thickness (mm)	Number of samples
1	CWM glued with MDF (both sides)	D-MDF (4mm), totally 40 mm	1
2	CWM glued with MDF (both sides)	D-MDF (6mm), totally 40 mm	1
3	CWM glued with pine solid wood (both sides)	D, Pine (7 mm), totally 65 mm	1
4	CWM glued with magnesite panel (both sides)	D, Magnesite (6 mm), totally 40 mm	1

The thickness of CWM door constructive solution samples was 40 mm (with MDF and magnesite panels cladding), while 65 mm was used for samples with pine solid wood gluing with an average density of 530 kg·m^{-3}. These thicknesses were used from previous predictions of reaction to fire properties. Solid pine wood has lower properties, so the thickness of the middle layer CWM was increased. Thickness of that means construction for external conditions are usually used. Previous mentioned materials from both sides were applied and EPI adhesive was used. Samples were tested in accordance with the requirements of LVS EN 13238:2015 standard and after, left in a conditioning chamber (temperature 23°C and relative air humidity 50%). Afterwards, the conditioning moisture content of samples was 10 ±1%. Mounting of the samples in a Single Burning Item (SBI) equipment was performed in accordance with the mounting scheme described in article 5.2.2.a of the standard by creating a ventilated air gap 80 mm behind the sample which is necessary for determination of the burn-through moment.

Results and discussion

During the test, CWM with magnesite panel cladding does not burn with an open flame. During the first 600 seconds after applying the flame to the sample, figure 2, CWM burning is not observed. The magnesite panel performs an enclosing function protecting the wood from heating up. Ten minutes later, pyrolytic gas is released causing a slight increase in the heat release rate.

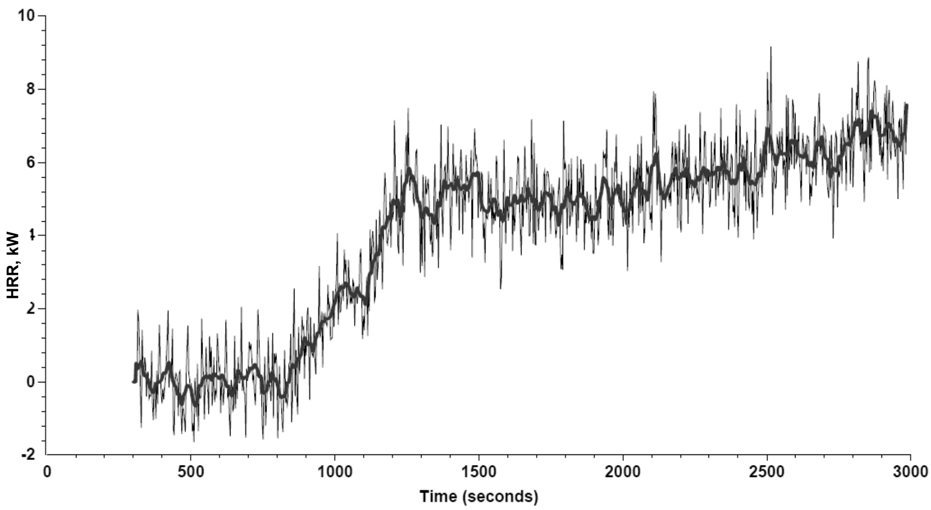

Fig. 2. Dynamics of burning capacity of the CWM covered with magnesite panel

During the test, a deformation and cracking of the magnesite panel was observed, caused by wood pyrolysis and shrinkage in volume, figure 3.

Fig. 3. CWM covered with magnesite panel after the testing

When the remains of the sample were analyzed after testing, the following positive feature was observed – CWM was completely charred while not burned through. The increased thickness of char provides a good thermal insulation which, combined with the magnesite panel's protective capacity, ensured a reduced wood charring rate of 0.5 mm per minute. Moreover, the magnesite plate demonstrated good mechanical resistance thanks to its inorganic fiber mesh.

Research with wood material facing – MDF and pine solid wood – showed considerably lower reaction to fire and potential fire resistance indicators, since the upper layer does not protect the material from ignition and temperature increase. As a result, the pyrolytic process starts faster and door leaf panel burns at a higher charring rate than solid wood in accordance with Eurocode 5 [LVS EN 1995-1-2+AC:2007]. CWM with MDF (thickness 4 mm and 6 mm) cladding showed a rapid burning of the material at the beginning of the test causing a heating capacity increase up to 80 kW, subsequently slowing down and creating a stable layer of coal; further on, the process runs steadily with a burning capacity of approximately 30 kW. Burn-through of samples was fixed by the heat release rate increase and visually, figure 4, when samples covered with MDF (thickness 4 mm and 6 mm) starts burning from the other side.

Similar observations were made with CWM with pine wood cladding. A summary of results can be seen in table 2. Solid wood faced door leaf panel, demonstrates the poorest result both in terms of reaction to fire performance and fire resistance indicators. In terms of reaction to fire performance specifications, all the materials with wood-based cladding can be graded as class D in reaction to fire performance classification system, while fibreboard cladding allows a layer of char to be maintained during the test which gives an all-over lower charring rate. The charring rate factor allows the prediction of the potential fire resistance limit of a door leaf element, not taking into account the joints in door construction.

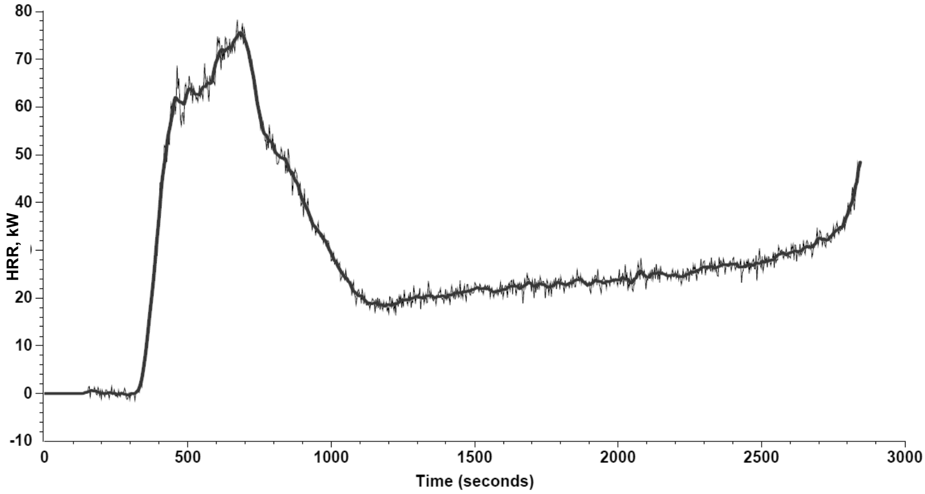

Fig. 4. Burning dynamics of CWM covered by MDF

Table 2. Characteristics of reaction to fire and charring

The thickness of facing material (mm)	Total thickness of door leaf panel (mm)	FIGRA ($W \cdot s^{-1}$)	THR 600s (MJ)	Time of burn--through (min)	Charring rate ($mm \cdot min^{-1}$)
D-MDF. 4 mm from both sides	40	331.0	29.7	36	1.1
D-MDF. 6 mm from both sides	40	413.0	31.3	40	1.0
D-Pine solid wood. 7 mm from both sides	65	674.5	31.8	36	1.8
D-Magnesite. 6 mm from both sides	40	6.100	0.20	56	0.5

The reaction to the fire performance test method cannot be applied directly to the determination of door fire resistance, since test methods are considerably different. The material combination tested – D-MDF-6 mm and D-Magnesite-6 mm showed potential to achieve the EI 30 min fire resistance limits.

Cellular wood material. has demonstrated a good potential for usage in the manufacturing of fire resistant doors which is further enhanced by high dimensional stability of the plate during burning. Multilayer cellular wood materials, composite reaction to fire performance basically depends on the upper layer properties. Nevertheless, it must be concluded that when combining cellular material with cladding material, such as 4 mm thick MDF, a good synergy of both materials can be observed. Each of them separately would be graded only as class E in reaction to the fire performance classification system, however, by creating a glued three-layer composite material panel, class D-s2-d0 in reaction to the fire performance classification system can safely be obtained with the performance equal to the solid wood burning process. Combining the cellular material with a product of mineral content facing, such as a magnesite board, a product with high fire resistance properties can be achieved. Such a composite material is meant to ensure a high resistance of upper layer against splitting and collapse.

Cellular wood material fire resistance properties were not studied in accordance with fire resistance testing methods, however, taking into consideration the conducted medium-scale reaction to fire performance test results, a well-founded hypothesis on potential fire resistance of the constructions can be put forward. Charring rate of cellular wood material could be approximately twice the rate of solid wood elements. Cellular wood material has a high potential in the improvement of fire safety specifications, since, due to the cellular structure, large amounts of fire retardants can be easily embedded into the wood. This could be the subject of the university's next research.

Conclusions

1. The reference samples with pine solid wood (thickness 7 mm) facing from both sides demonstrates the poorest result both in terms of reaction to fire performance and fire resistance characteristics.

2. In terms of reaction to fire performance specifications, all the materials with wood-based facings can be classified as class D, while medium density fibreboard facing allows a layer of char to be maintained during the test which gives an all-over lower charring rate.

3. The burn through time of a door leaf composite panel allows prediction of the potential fire resistance limit.

4. The material combinations tested - D-MDF-6mm and D-Magnesite-6 mm showed the potential to achieve the EI 30 min fire resistance limits.

5. Cellular wood material has demonstrated a good potential for usage in the manufacturing of fire resistant doors which is further enhanced by high dimensional stability of the door leaf during the combustion process.

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List of standards

LVS EN 1995-1-2+AC:2007 Eurocode 5 – Design of timber structures. Part 1-2: General – structural fire design

LVS EN 13823:2015 Reaction to fire tests for building products – building products excluding floorings exposed to the thermal attack by a single burning item

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