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New Technology for the Continuous Production of Wood-based Lightweight Panels

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Abstract

Lightweight boards in the wood-based panel and furniture industry are not a new topic. First trials to reduce the density of PB and MDF boards were mentioned more than one decade ago. Sandwich panels with faces from thick veneer, plywood, thin PB or MDF and cores made from honeycomb paper, very light wood species or foams are also state of the art since at least two decades. The fast growing market of knockdown furniture on the one hand and the increasing costs for energy and raw materials on the other hand are additional factors that make weight saving a primary economical objective for most panel producers. Moreover, customers demand more for ergonomically solutions regarding packaging and transportation. A new one-stage production process for sandwich panels with wood-based facings made from veneers, wood particles or fibres and a core consisting of expandable particles is presented. It could be integrated in existing continuous pressing lines for PB and MDF manufacturing keeping the advantages of this production technique in matter of efficiency. The manufacturing of lightweight sandwich panels in a continuous one-stage process should combine the production of the dense facings and the very light core layer. During the first stage of the hot pressing process, the mat surfaces are compacted to high densities and the resin cures in this state. In a second stage, the press is opened to the final panel thickness. In this stage, the foam material expands and forms the lightweight core. The core material itself acts also as a bonding matter to the facings. The lightweight panels that were produced at lab scale reveal mechanical properties that are comparable to recently used wood-based panels while obtaining a weight reduction of 30-50%.

Keywords: light composite board, sandwich panel, foamed core, continuous pressing

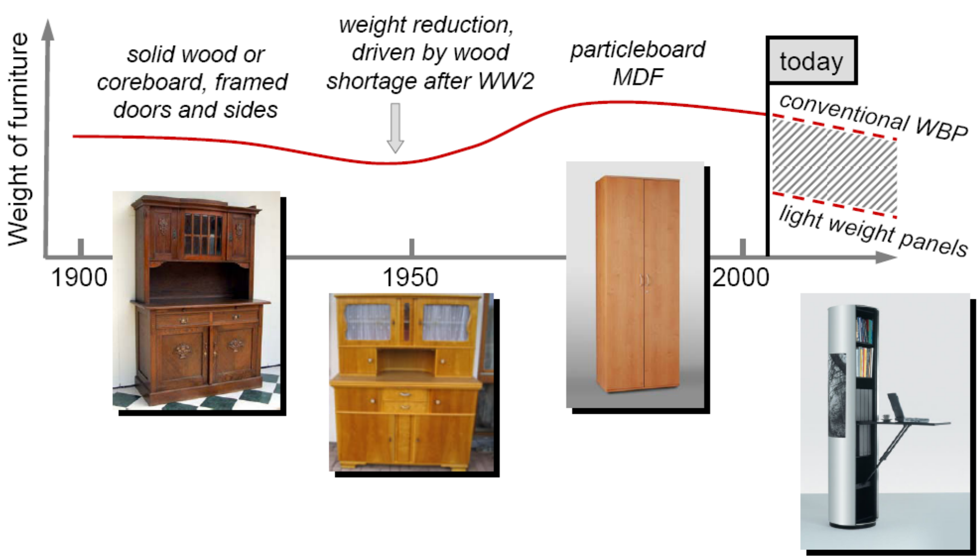
Introduction

The lightweight wood-based panel industry developed in the last two decades in different ways. The reduction of density for particleboard (PB) and medium density fibreboard (MDF) using light available wood species, increased resination and optimized board density profiles is well proved as an industrial technique. This way allows a reduction by maximum one third of the initial density and keeps the main properties like internal bond (IB) and bending strength (MOR) in an acceptable range. The production costs could be a problem for manufacturers not having available light species or no facilities to produce their own resin, because of their increased resination. The costs for material make up for more than 50 % of the total manufacturing costs. The new generation of light panels (especially >19 mm) reaches densities of 500 kg/m³ for MDF and 450 kg/m³ for PB but their fields of application became limited.

Despite the booming development of MDF in the last two decades and its excellent properties and processability, PB continues to keep in first place in terms of market shares in the world (36%) and in Europe (61%) (Davies, 2001). Main advantages of PB compared to MDF or plywood that can explain this situation are the possibility to use 100% recycled wood, to produce low weight panels at a low price. In some regions the processing and finishing technologies, which are limited only to PB might also be a reason for its supremacy.

The European furniture industry is processing 54 % of PB (38 mill.m³) and 55 % of the MDF (13 mill.m³) production. The high densities of these panels cause high end product weights (Fig.1). Especially the fast-growing market for knockdown furniture demands low weight furniture (Barbu et.al., 2008). New considerations imposed by take-away furniture chains limited the package weight in order to meet dimensions that match the ergonomic abilities for the end-users. Heavy pieces of furniture have to be split into more than one package. A maximum weight of 25 kg per unit seems tolerable in this context (Stosch, 2009). However, by decreasing the weight of the individual pieces of furniture, handling can be also simplified once the product is assembled. This reduces the risk of damages and extends the service life of the product (Frühwald et.al., 2009).

Figure 1. Development of furniture weight (Thömen et.al., 2007)



In the early 20th century, the weight of pieces of furniture decreased significantly. The reason was not the demand for lightweight materials but rather the shortage of wood after World War II. With the apparition and use of PB and MDF, the weight of furniture increased. Only in the recent years, lightweight design has become its own, independent subject that aims at improving functionality, reducing cost and ecological impact (Wiedemann, 2007).

Objectives

As the production of lightweight panels is more elaborate and raw material costs like foams or expandable materials are often higher compared to most standard boards. The advantage of lightness is counterbalanced by the increased prices for the final panel (Lüdtke et.al., 2007 and Michanickl, 2006). If production processes become more efficient by innovative solutions up to 30 % of the produced thicker wood-based panels (> 20 mm) could be substituted by lightweight panels (Frühwald et.al. 2009). The recent decrease of classical board prices (especially PB and MDF) is still an impediment for a short-term market implementation of the modern lightweight boards independent of their performances.

Some furniture design developments of the last three decades like thin elements, straight surfaces, local joints and the use of melamine or veneer-coated surfaces allow and request again the use of lightweight wood-based panels. The established technology for producing honeycomb sandwiches with timber frames and thin faces was optimized and reused recently to reduce weight by up to 50%. Some shortcomings of the honeycomb sandwiches still are limitations for the market success: sizes, fix frame position in the panel, low resistance to parallel loads and low price performance for thin boards (<24 mm) (Poppensieker et.al. 2005 and Thömen, 2008).

However, classical wood-based panels like PB with partially reduced weight (>450 kg/m^3) represent a strong competitor in terms of volumes and low prices. Some lightweight sandwich panel producers using classical discontinuous processes could not penetrate all possible application fields because of this situation (Michanickl, 2006).

Different techniques to save weight in wood-based panels show individual downsides. Either the production of lightweight panels is too laborious, which in many cases means too costly, or the mechanical and physical performances of the panels are significantly decreased. With a growing number of benefits that lightweight panels are supposed to deliver, i.e. decreasing weight and material costs and an increasing flexibility, the challenges increase. Lightweight panels with large cells in the core request very sophisticated solutions concerning fittings, edge processing and – lamination. One solution is the use of sandwich panels with a foam core. As cell sizes of the foam material are very small compared to tubes or honeycombs, problems with the heterogeneity of the core, like edge-processing or "telegraphing" effect on the surface are negligible. Moreover, foam cores often introduce thermal insulation properties. However, the material input increases constantly with increasing thickness of the boards, while the use of thicker honeycomb panels introduces growing empty spaces in the panel, which decreases the relative costs. This is one reason why honeycomb panels become cost effective in thicknesses greater than 24 mm (Poppensieker et al., 2005). For standard thicknesses from 15 to 19 mm, foam core panels can present a competitive alternative.

This paper describes recent techniques and presents a new technique for the production of foam core panels with wood-based facings. Additionally, some characteristics of panels produced at lab scale are presented.

Recent Production Techniques

A sandwich panel generally comprises of three layers. The core, a comparatively thick layer, separates two thin surface layers, or facings. The main function of the core is to keep the facings at a certain distance. The core only bears lower shear stresses and thus can be very light (Allen, 1969). The compression and tension stresses are highest in the facings, thus the facing structure has to be very strong. This provides very good static properties with respect to weight.

Two recent ways of producing lightweight sandwich panels are described. Discontinuous production techniques use pre-expanded foams for the core and thin boards or foils for the facings. The core material is usually foamed and then sliced from a block. The slices are glued on prefabricated and coated thin panels like thick veneers, thin PB, plywood or MDF. In consequence, three individual steps are necessary to produce a foam-core sandwich panel. By using this technique, however, it is possible to use wood fibre based facings, because prefabricated wood-based facings cannot be further processed in a continuous manner as of their fixed dimensions (Davies, 2001). The high production costs caused by the discontinuous batch process and limited sizes are counterbalancing the important weight reduction that is possible using this technique.

Continuous processes are used when it comes to materials that can be fed into a processing unit in a virtually endless manner, like from a coil. Compared to the discontinuous process, this technique uses less individual steps for the assembly of sandwich panels. Here, only prefabricated facings like foils or impregnated papers are used, while the core is in most cases foamed between the facing during the production process. Due to the adhesion properties of the foam - usually PU-foams are used - no additional gluing layer is needed. This technique is preferable not only from an economic point of view, because the output is higher and the input of labor and material is less. In addition, quality aspects reveal that a continuous manufacture generates more stable panel conditions and more diverse sizes (Fig. 2).

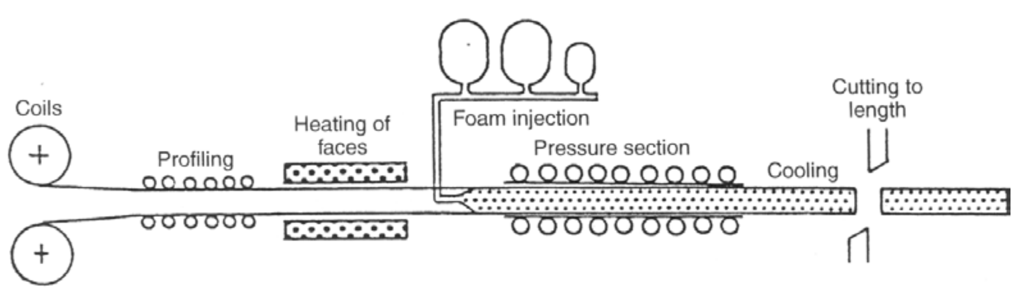


Figure 2. Principle of a continuous foam core panel production (Davies, 2001)

Novel foam core panel process

Recently, the authors reported about a novel approach for the continuous production of foam core sandwich panels with wood-based facings (Lüdtke et.al. 2007). In this approach, the manufacture of the facings and the core takes place during the continuous hot pressing of the sandwich panel. The approach is derived from the conventional production technique of wood-based panels (PB and MDF) and was designed with a continuous production in mind although not limited to.

Figure 3a shows the principle of a conventional PB process. A three-layered mat composed of resinated wood particles, coarse particles in the core and fine particles in the surface layers, is formed using three individual forming heads. The mat is then pressed in a continuous hot-press. In comparison Figure 3b shows the novel foam core process. A three-layered mat is formed consisting of two resinated yet not compacted face layers and one unexpanded core layer. The face layers comprise of resinated wood fibres or particles. The core layer is composed of a dry expandable thermoplastic material, which is triggered by temperature. After the compaction of the facings, the temperature in the core initiates an expansion.

Shortly after, the press is opened to the desired panel thickness. After a consolidation phase, the panel is ready for cut-to-sizing.

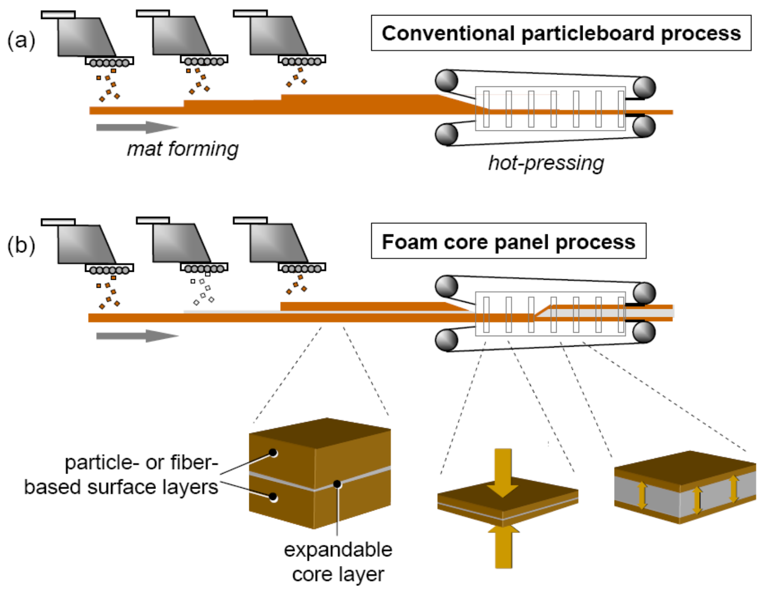
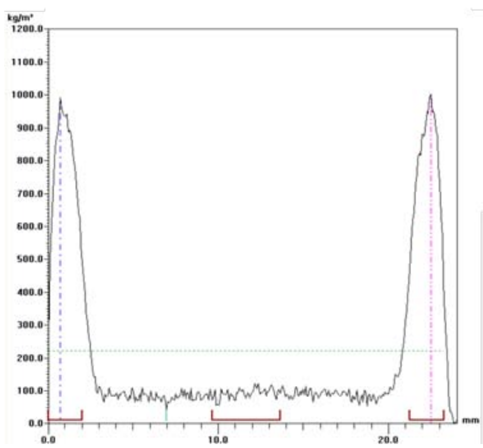


Figure 3. Principle of the one-stage process, (a) conventional particleboard process (b) foam core panel process (Thömen, 2008)

Light weight sandwich panels properties

Sandwich panels were produced at lab scale according to the new continuous production technique with a target thickness of 19 mm. The surface layer was made from UF resinated softwood particles used in the PB industry. The manufacture of the samples was done on an 800x600 mm² lab hot-press following the process described above. The surface thicknesses of the panels were varied in three steps between 3 and 5 mm. During the trials, the amount of foam material in the core was unchanged. The UF resin content in the surfaces was set to 12 % (solid) for all sandwich panels. The tested properties were bending strength (MOR) according to EN 310 and internal bond (IB) according to EN 319.

Figure 4 shows a cross-sectional density profile of a 19 mm thick sandwich panel with 4 mm facings and an 11 mm core layer. The average panel density is 380 kg/m³. The facings density is up to 880 kg/m³, while the core shows an average density of 160 kg/m³. The graph shows that the cross-sectional profile of the panels is highly symmetrical. Other variations with 3 mm and 5 mm thick facings hold average densities of 310 and 510 kg/m³, respectively.
The same applies for the thickness of the core.



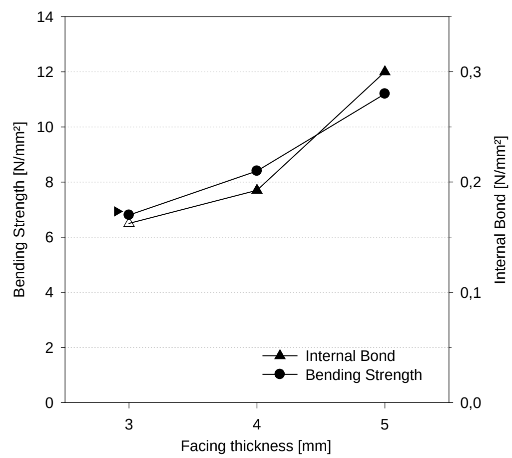


Figure 4. Density profile of a sandwich panel with wood-based facings (Frühwald et.al. 2009)

Figure 5. Development of bending strength and internal bond strength with increasing surface thickness (Frühwald et.al., 2009)

The overall density can be adjusted from 200 to 600 kg/m³. This is possible since the thickness of the facings can be as low as 0,5 mm while there is no technical upper limit.

Figure 5 shows the development of MOR and IB with increasing facing thickness. Due to the increasing planking effect of the surface layers, the MOR increases significantly with facing thickness. The average MOR for 3 mm surface layers reaches 6,5 N/mm², for 4 mm surfaces 7,7 N/mm² and for 5 mm surfaces 12 N/mm². The higher compaction of the foam with thicker facings resulted in a more shear resistant core. The crack formation changed correspondingly from shear failure to face yield in the lower facing. The IB test revealed a similar trend. Thicker facings resulted in superior internal bond values as 0,17 N/mm² for 3 mm facings, 0,21 N/mm² for 4 mm and 0,28 N/mm² for 5 mm surfaces, respectively. All samples failed at the interface between the wood particle facing and the foam core.

As the polymer was mixed with wood particles to optimize the scattering behaviour, the embedding of the wood inside the foam was investigated. Figure 6 shows a transition zone between the surface layer (bottom) and the foam core (top). The compaction of the surface fibres indicates a high density, which was not influenced by the polymer separating the surface layers during production. The interface between the facing and the core is form-fitting. The bonding is defined by the adhesion quality of the polymer. The magnification reveals a good embedding of the wood particles in the expanded foam material so that the particles seemingly do not present flaws.

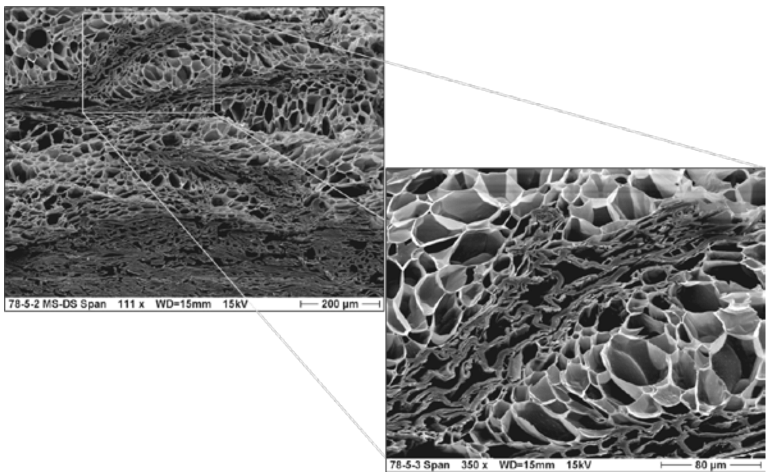


Figure 6. Interface between facing and core and structural integrity of wood particles in foam

Further developments

Based on previously gained experience with the lightweight sandwiches, **plywood with a foam core** in one single production step was manufactured. On laboratory scale, was produced a mixture of expandable material and wooden particles between surface layers, consisting of two or three conventionally glued veneers. The pile was placed in a hot single-opening lab press and compressed and heated until the glue between the veneer layers was cured. After the reaction temperature for the expandable material in the middle layer was reached and the expansion began, the lab press was opened to the desired panel thickness, allowing the foam in the core to expand. After stabilizing the foam in the press, the sandwich-type plywood can be further processed.

Knowing that a core consisting of a mixture of wooden particles or fibres and a powder between veneers does not really fit into the production process for plywood, the expandable material should be placed in to a prepreg sheet, which allows an easy handling. Such an expandable layer, or several of them, could be placed between the veneers forming the facings of the sandwich-type plywood composite. This method could be applied for producing flat panels and **3D moulded parts** as well.

Together with Papier-Technische Stiftung (PTS) in Munich/Heidenau a **paper-based foam prepreg** was developed. The expandable material is a very fine powder which can be dispersed in water. Cellulose fibres, expandable powder and water form a slurry-type mixture which can be processed into a paper-like sheet material on a paper machine. Based on the experience gained mixing wood fibres and expandable powder material (Fig.6), similar results using the cellulose fibres and expandable microspheres in a paper-type foam prepreg (Fig.7) are expected.

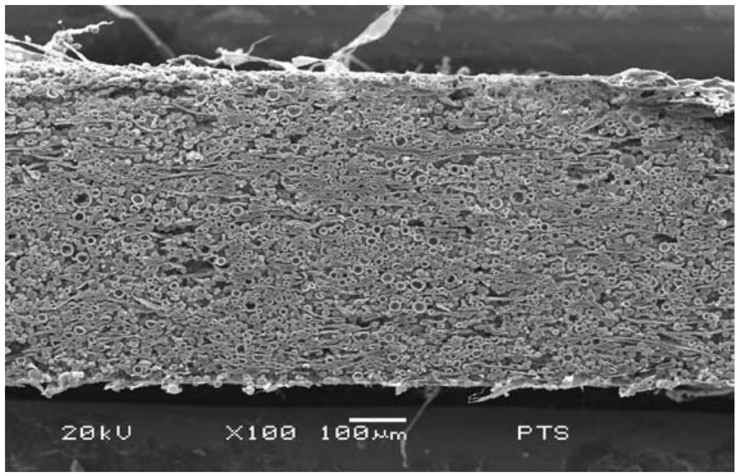


Figure 7. Unexpanded microspheres embedded in a cellulose fibre matrix (prepreg)

PTS produced a paper-like sheet consisting of 60 % expandable microsphere powder and 40 % cellulose fibres. Figure 9 shows a cross section of the paper-based prepreg with unexpanded microspheres embedded in a cellulose fibre matrix. This heavy loaded paper will have the ability to expand to a final thickness of at least tenfold its initial thickness. This gives the paper a veneer-like characteristic and opens up the possibility to lay up the paper in uneven shapes so that three dimensionally formed panels can be produced.

Conclusions and Outlook

The growing demand for lightweight panels is met by the wood-based panel industry with the development of different weight saving opportunities. One way of saving weight is the reduction of raw material and adjusted gluing systems (also increased resination); another way is the breakup of the structure. Lightweight design as its own discipline contributes several concepts in this context, like the structural advantages of sandwich layouts. The new one-stage process improves the efficiency and can be used to produce light sandwich panels with wood-based facings continuously. The mechanical properties of the panels are, with respect to weight, comparable to classical wood-based panels. The panel composition can be varied in wide ranges. At the same time, the panels are not depending on a frame construction. Against the background of a growing freedom in design for furniture manufacturers and the need for efficient production techniques, this development does seem to be an alternative for recently used production techniques.

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