Development and Characterization of Oriented Strand Boards made from the European Hardwood Species: Beech (*Fagus sylvatica* L.*)* and Poplar (*Populus tremula* L.)

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ENGLISH REVIEW TESTIMONIAL

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Summary

Oriented Strand Board (OSB) is an important wood engineered product widely used around the world in both the residential and commercial wooden structures. Increasing demand for OSB, especially in the construction sector, and the search for suitable raw materials, in terms of properties and price, present the main challenges for board producers and scientists alike.

In Europe, almost all OSB producers use Scots pine (95 %) and spruce as raw materials for OSB production. This is because these species are easy to manufacture, process good board properties and availability (in volumes) and, in most OSB production countries, they are reasonably priced. The competition between pulp and paper industries, even more notably the rapid development of the wood energy (mainly pellets) sector, and rising demand for wood based panels made of pine has increased pressure on softwood forests. In addition, pine based OSB emits high levels of VOC (volatile organic compound) which is growing concern in Europe. Therefore, finding new raw materials to replace all or most of these demands is a golden key for the future development of this market.

The main goal of this project was to test the technological potential of using small diameter beech and poplar as two important hardwood species which are available in most of European countries. The research design includes the use of two wood species in different combinations, i.e. different mixture of the two species, varied face/core ratios and two different board densities. All technical properties of the produced panels fulfilled the minimum requirements for OSB type the 2 of EN300 standards with exception of panels made of 75 % poplar core layer (details are given in the table).

The study also examined the use of fine strands as core material and its effect on the physical and mechanical properties of European beech and poplar OSB. Fine material is an important part (10-15 %) of the strand production which is collected after strand drying. Often it is used for producing particleboard, but many OSB producers use at least part of it as core material. The findings of this project indicated that using hardwoods like beech and poplar combined with board core layers consisting of up to 30 % of fine

materials could introduce a different type of OSB to the market. The mechanical properties such as MOR and MOE and also internal bond reach the minimum requirements for OSB type 2 (EN300).

In order to test the combinations of all potential species OSB was also made from beech, poplar and pine were produced. Out of the different combinations the mixture of beech and poplar showed the best board properties at comparable board manufacturing criteria.

In addition, the study tested some other important parameters such as vertical density profile, volatile organic compound emission, and the effect of different wood species on densification behavior during hot pressing as well as the influence of strand geometry and different face/core ratios on physical (thickness swelling & water absorption) and mechanical properties (modulus of rupture, modulus of elasticity, and internal bond).

The results of this research project proved the potential for beech and poplar as a good substitution for the current raw material pine. Beech and poplar could also be used in place of or in a different mixture with pine or the three wood species respectively. The use of beech and poplar could reduce the concerns regarding volume and cost effective raw material supply for the OSB industry in the near future and could also reduce the pressure on softwood forests in Europe.

Table 1. Overview of physical and mechanical properties of OSB

Laboratory board design	Laboratory boards with density							
	650 (kg/m^3)				720 (kg/m^3)			
	MOR	MOE	IB	TS	MOR	MOE	IB	TS
Min. requirement EN 300 (OSB 2)	20	3500	0.3	20	20	3500	0.3	20
100% beech	35.8	6317	0.4	16	52.5	6888	0.7	12
100% poplar	23.7	4980	0.3	19	42.4	5443	0.6	23
50 % b (face) / 50% p (core)	39.5	4956	0.5	12	49.3	5843	0.5	20
50% p (face) / 50% b (core)	47.8	5310	0.6	13	50	6050	0.7	9
B (face) / 30% p fine (core)	56.4	7523	0.99	12	n.t	n.t	n.t	n.t
P (face) / 30% b fine (core)	39.2	8464	0.46	21	n.t	n.t	n.t	n.t
Mix beech & poplar	61.7	6839	0.87	13	69.3	7031	1	6.6
Mix beech & pine	47.6	6951	0.91	23	65.2	8174	1.31	24
Mix poplar & pine	56.8	6769	0.61	16	58.5	7004	1.1	18

B: beech, P: poplar MOR, MOE & IB (N/mm^2), TS (%) n.t: not tested

Zusammenfassung

OSB Platten sind ein wichtiger, ausgereifter Hololzwerkstoff, der in der Welt sowohl im privaten Hausbau als auch in öffentlichen Gebäuden eingesetzt wird. Die vor allem in der Baubranche steigende Nachfrage nach OSB und die Suche nach geeigneten Rohstoffen im Hinblick auf Eigenschaften und Preis, stellen die wichtigsten Herausforderungen für die Plattenhersteller und Wissenschaftler dar.

In Europa verwenden fast alle OSB-Hersteller Kiefer (95 %) und Fichte als Rohstoffe für die OSB-Herstellung, da diese Arten leicht zu verarbeiten sind und gute Platteneigenschaften zeigen, die Verfügbarkeit (in Volumen) gegeben ist und in den meisten Ländern diese Holzartenpreiswert für die OSB-Produktion sind. Die Konkurrenz zwischen der Zellstoff- und Papierindustrie, zudem die rasante Entwicklung der Holzenergie (vor allem Pellets) Sektor und die steigende Nachfrage nach Holzwerkstoffplatten aus Kiefer hat den Druck auf Wälder erhöht. Darüber hinaus gibt aus Kiefer hergestellt OSB hohe VOC (flüchtige organische Verbindung) ab, was derzeit in Europa diskutiert wird. Daher ist die Suche nach neuen Rohstoffen für die meisten dieser Anforderungen eine Herausforderung, deren Lösung weitreichende Veränderungen für die zukünftige Entwicklung dieses Marktes darstellt.

Das Hauptziel des Projektes war es, das technologische Potenzial der Verwendung von Partikeln kleiner Durchmesser von Buche und Pappel, welches wichtige Laubholzarten sind und in den meisten europäischen Ländern verfügbar sind, zu testen. Das Forschungsdesign umfasst den Einsatz von zwei Holzarten in unterschiedlichen Kombinationen, d.h. unterschiedliche Mischung der beiden Arten, variierte Deckschicht-/Mittelschichtverhältnisse und zwei verschiedene Plattendichten. Alle technischen Eigenschaften der hergestellten Platten erfüllten die Mindestanforderungen für die OSB-Typ 2 Platte nach EN 300 mit Ausnahme von Platten aus 75% Pappelkernschicht (Einzelheiten sind in der Tabelle angegeben).

Die Studie untersuchte auch die Verwendung feiner Strands als Kernmaterial und seine Ausirkung auf die physikalischen und mechanischen Eigenschaften der Buchen- und Pappel-OSB. Feines Material ist ein wichtiger Teil (10-15%) der Strandproduktion, die nach dem Trocknen der Strands anfallen. Oft warden diese für die Herstellung von Spanplatten verwendet, einige Hersteller verwenden diese teilweise als Kernmaterial bei der OSB-Produktion. Die Ergebnisse dieses Projektes haben gezeigt, dass die Verwendung von Harthölzern wie Buche und Pappel kombiniert mit Mittelschichten, bestehend aus bis zu 30% der feinen Materialien möglich ist und eine alternative OSB auf dem Markt aufzeigt. Die mechanischen Eigenschaften wie Biegefestigkeit, E-Modul und Querzugfestigkeit erreichten die Mindestanforderungen für OSB Typ 2 (EN300).

Um die Kombinationen aller potenziellen Arten zu testen wurde OSB-Platten auch aus Buche, Pappel und Kiefer produziert. Aus den verschiedenen Kombinationen zeigte die Mischung aus Buchen-und Pappelholz die besten Platteneigenschaften bei vergleichbaren Plattenkriterien.

Darüber hinaus wurde in der Studie einige andere wichtige Parameter wie das vertikale Dichteprofil, VOC-Emission, und die Wirkung der verschiedenen Holzarten auf Verdichtungsverhalten beim Heißpressen sowie dem Einfluss der Strandgeometrie und andere Deckschicht-/Mittelschischtverhältnisse auf die physikalischen (Dickenquellung und Wasseraufnahme) und mechanischen Eigenschaften (Biegefestigkeit, E-Modul und Querzugfestigkeit) getestet.

Die Ergebnisse dieses Forschungsprojektes bewiesen das Potenzial für Buche und Pappel als guter Ersatz für den aktuellen Rohstoff Kiefer. Buche und Pappel könnten auch anstelle von oder in einer anderen Mischung mit Kiefer verwendet werden. Die Verwendung von Buche und Pappel könnte die Bedenken in Bezug auf Volumen und kostengünstige Rohstoffversorgung für die OSB-Industrie verringern und zudem den Druck auf die Weichholz-Wälder in Europa senken.

Table 1. Überblick von physikalischen und mechanischen Eigenschaften von OSB

Laborplatten-Design	Laborplatten nach Dichte							
	650 (kg/m^3)				720 (kg/m^3)			
	MOR	MOE	IB	TS	MOR	MOE	IB	TS
Anforderungen nach EN 300 (OSB 2)	20	3500	0.3	20	20	3500	0.3	20
100% Buche	35.8	6317	0.4	16	52.5	6888	0.7	12
100% Pappel	23.7	4980	0.3	19	42.4	5443	0.6	23
50 % B (DS) / 50% P (MS)	39.5	4956	0.5	12	49.3	5843	0.5	20
50% P (DS) / 50% B (MS)	47.8	5310	0.6	13	50	6050	0.7	9
B (DS) / 30% P fine (MS)	56.4	7523	0.99	12	n.t	n.t	n.t	n.t
P (DS) / 30% B fine (MS)	39.2	8464	0.46	21	n.t	n.t	n.t	n.t
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B: Buche, P: Pappel MOR, MOE & IB (N/mm^2), TS (%) n.t: not tested

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List of Abbreviation

B	Beech
CO2	Carbon Dioxide
CLT	Cross Laminated Timber
EN	European Norms (Standard)
FAO	Food and Agriculture Organization
Fig	Figure
FPS	Forest Product Society
GLT	Glue Laminated Timber
H	Hour
Ha	Hectare
IB	Internal Bond
ISO	International Organization for Standardization
MDF	Medium Density Fiberboard
MDI	Methylene Diphenyl Diisocyanate
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
MUF	Melamine Urea Formaldehyde
OSB	Oriented Strand Board
P	Poplar
PB	Particle board
PF	Phenol Formaldehyde
PMDI	Polymeric Methylene Diphenyl Diisocyanate
TE	Toluene Equivalent
TS	Thickness Swelling
UF	Urea Formaldehyde
VDP	Vertical Density Profile
VOC	Volatile Organic Compound
WA	Water Absorption

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I would also like to thank my parents, sister and brother for their love, care and encouragement during my studies.

1 Introduction

Oriented Strand Board (OSB) is an important wood engineered product used in both residential and commercial wooden structures throughout the world. The first attempts to produce OSB were made during the 1960's and 1970's based on previously produced wafer-boards (Maloney 1993) and early flake-boards from Novopan Company (Switzerland / Germany) during the 1950's. USA and Canada contributed around 80 % of the OSB production and have continued as leaders in the wood based panels market (Thoemen et al. 2010). Since 1990, new mill startups have increased the number of OSB mills worldwide to 65 mills, while production capacity has increased by more than 100 %, to a record 28 billion square feet per year in North America (Adair 2005). The first pilot plant in Europe began operating in 1978 (Thoemen et al. 2010).

Although OSB is not a new product in Europe, in 1990, market demand for this type of building element began to rise significantly.

The increased demand for OSB has positive effects on the market and could be viewed as good news for producers, but concerns regarding sufficient raw material, availability, price, and environmental issues are other aspects that need to be addressed in order to draw a well rounded conclusion.

Almost all OSB producers in Europe use Scots pine (95%) and Spruce as raw material for OSB production. Germany is the leading producer in Europe with a production level of 1.2 million m^3 (Fig. 1). Pine oriented strand boards demonstrated good properties in physical and mechanical requirements and pine strands combined with phenolic resin (PF) or pMDI (polymeric diphenyl methane diisocyanate) could cover the requirements for the structural sector. But the exclusive use of pine (or spruce) as raw material led to a huge pressure on softwood round wood market.

On the other hand, environmental concerns and stricter regulations in Europe present another challenge to using current or new raw material for OSB.

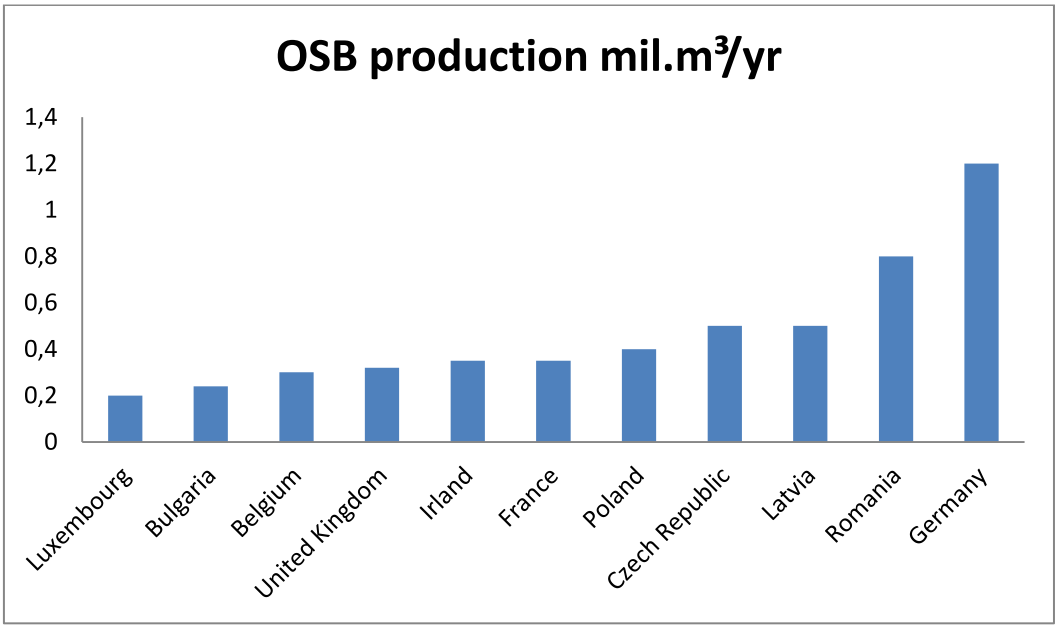


Figure1. OSB producers in Europe (end of 2011) [Source: EPF 2011-2012 & WBPI 2012]

Despite the good quality of oriented strand boards made of pine, the volatile organic compound (VOC) emission is still a big challenge of pine species for producers. Therefore, increasing pressure on softwood forests and VOC emission are drawbacks concerning newer options on environment in Europe. Substitution of pine as raw material for OSB seems necessary. Although some researches (Beck et al. 2009) have been started in this field but there are not in large scale or in practice.

Within the EU 27, the main area covered by forest represents 41 % (177.8 mill. ha). Only 132.6 million ha (75 %) are suitable for round wood production (Barbu 2012). In addition, the new policy in Europe is based on converting softwood forests to future hardwood forests for ecological and sustainability reasons. Therefore, a shift in thinking and more concentration on hardwoods could be a golden key to finding an alternative raw material for the OSB market in Europe. Table 2 shows wood based panel productions in Europe.

Table 2. Wood based panels production in Europe, in 1,000 m³, 2011

Europe	MDF	PB	OSB	Plywood
Western & Central	7810	15806	2720	2319
Eastern	3240	9035	2440	2202
Northern	110	1595	0	1869
Southern	3955	6677	160*	3483
Total	15115	33113	5160	9873

*Start up in Italy 2013 based on poplar Sources: EPF 2011-2012, FEIC

Beech is the most wide spread hardwood species in Western and Central Europe. In northern Europe, beech grows at low elevations while in southern Europe it is found also at altitudes above 1000 m. The eastern part of Europe also has good availability of beech such as Czech Republic, Slovakia, Romania, and Hungary with the actual area (% forest area) of 5.8 %, 30.4 %, 30.7 %, and 6.3 %, respectively (Hort et al. 1999, Saniga 1999, Zielony 1999, Giurgiu et al. 2001).

France, Italy and Turkey are three main producers in Europe of poplar plantations (479000 ha). There is also a very good potential for poplar plantations in Hungary (109.300 ha) and Romania (55.300 ha) (Barbu 2013, Coaloa & Nervo 2011).

Objectives

The main goal of this project was to examine the possibility of using beech (*Fagus sylvatica* L) and poplar (*Populus tremula* L) which are available in most of European countries as two main hardwood species for the panels industry.

To investigate the technical feasibility of using beech and poplar for OSB, two strategies were developed:

First, to use the single species for boards, and the second to use it as mixture. These strategies comply with the material availability and the technological feasibility. Other aspects of this project were:

a) Producing a mixture of beech and poplar strands and also combined with pine to determine the differences between single material “pure” panels and mixed species OSB

b) Comparing panels made with beech and poplar with pure pine panels

c) Using the fines of beech and poplar in core layer and the effects on physical and mechanical properties to find the optimum fines content with to fulfill the EN standard requirement for OSB

d) Densification and behavior of veneer stripes during hot pressing, with and without resin at different press temperatures to study densification behavior

e) Measuring volatile organic compounds emission (VOC) of beech and poplar panels and compare to the pine OSB

2 State of Knowledge

This chapter reviews the history and previous research available in relation to different aspects of this research project. In the first part, the history and background of OSB manufacturing is reviewed. In the second, the current situation of hardwood and softwood forests in Europe and Germany are studied. After, a short explanation about different characteristics of beech and poplar wood used in this project, a short description and history of wood/ veneer densification, permeability, and the chemistry of pMDI resin and the background of using this resin in wood based panels industry will be explained.

Furthermore, Resin penetration in wood, reasons and problems with volatile organic compounds emission from OSB are added.

2.1 History and Technology of Oriented Strand Board (OSB)

Oriented strand board (OSB) is an important wood engineering product that consists of strands combined with water resistant / thermosetting resins pressed at high temperature in hot press. Unlike particle board and medium density fiber board that are used mostly for furniture and interior application, OSB is used mainly for load bearing products in both commercial and residential buildings. Therefore, a suitable binder for moisture resistance and long term load bearing is one of the essential elements of OSB production. The largest OSB market is the structural panel market (IRSI 2002). OSB has captured more than half of the structural panel market in the last two decades (Barbu 2011).

Typically, the main glues used in OSB production are phenol formaldehyde (PF) and polymeric dimethyl diisocyanate. The new trend in Europe is to glue the faces and core with 3-6 % and 4-10 % PMDI respectively (depending on OSB type) (Thoemen et al. 2010). In order to reduce total VOC’s emission many OSB producers use pMDI exclusively.

Plywood and OSB are two wood based products which are used for construction process. Basically both products are designed as 3 layers composite where the middle or core layer is oriented 90° to top and bottom layers.

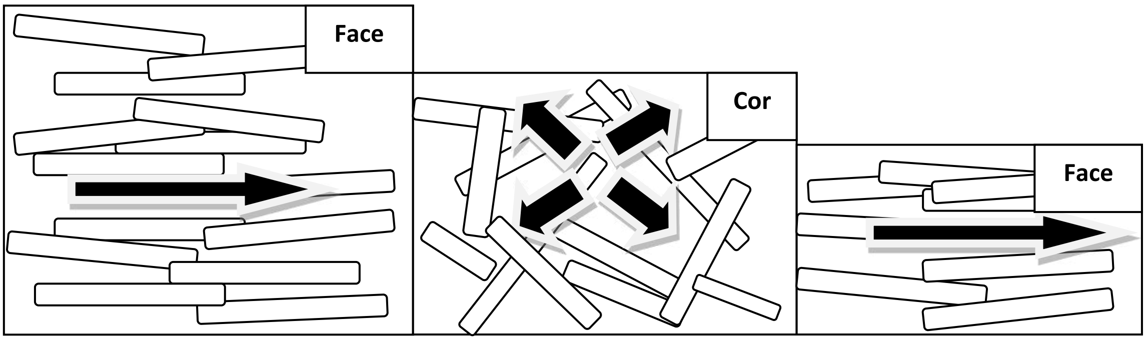


Figure 2. A schematic OSB layers

But the main difference between plywood and OSB is the geometry of material. Plywood requires high quality wood veneer that is produced by peeling. For this reason, high quality and large diameter of logs from old growth forests are necessary. Supplying suitable logs as raw material for plywood is the greatest challenge for this market. The technology of peeling smaller diameter logs (starting from 15 cm diameter) is generally available and yield of veneer is lower, processing costs are higher, and veneer technological quality is lower. For OSB production small diameter logs could be used as well as the peeler cores from peelings. Generally, the shape of strands is rectangular with a length between 70 to 150 mm, a thickness of less than 1 mm, and varying in width between 10-25 mm. The main quality indicator for strands is the ratio between length and thickness that is called slender mass ratio. Nelson (1997) cites strand geometry as crucial in obtaining optimum board properties. The slenderness ratio (L/d where L is the strand length and d is the strand thickness) has often been used to develop empirical equations specific (Meyer 2001).

Reviewing the history of OSB clearly shows that it went through several developments before it successfully became part of a competitive stable market. A key factor influencing future market volume is the shortage of suitable raw materials. One example already mentioned in this context is plywood. The shortage of large diameter logs grown under optimum conditions used to produce high-quality plywood necessitated research into new market opportunities for a wood-based product with the same or even better properties than plywood. OSB was found to be a very good solution around 30 years ago.

The advantages and disadvantages of OSB compared to plywood are listed below:

Advantages

- Cheaper production process in terms of lower materials and processing costs
- Using smaller diameter logs
- More decay resistance
- Manufacture as large sheet
- More uniform
- Smaller dimension tolerances

Disadvantages

- Lower strength and stiffness
- Lower resistance to water

James Clark developed the first manufacturing facility to produce waferboard at Sand Point, Idaho in 1950 (Huber 2002). A decade later, MacMillan Bloedel operated the first commercial waferboard plant at Hudson Bay, Saskatchewan/ Canada. Blandin Wood Products of Grand Rapids, Minnesota was the first successful U.S. waferboard producer. Waferboard technology soon gave way to OSB for its superior mechanical properties.

The first OSB was fabricated in Canada in 1964 but it did not find its solid status in the market until the mid-1980s (Hiziroglu 2009). Today, almost 80% of global production capacity is produced in North of America and Canada (Thoemen et al. 2010, Barbu 2012)

Europe operates 15 factories with a total capacity of 5 million m^3/year by the end of 2013 (incl. Russia and Turkey) and this amount will increase to 7 million m^3 by the end of 2019. The only OSB mill in Asia is located in China since 2010 (Anonymous 2012).

OSB is commonly used for wall sheathing, floor construction, roof cover and I-joist beams in both commercial and residential buildings. OSB also is used in furniture, reels, trailer liners, and recreational vehicle floors. In Europe, more than 50 % of OSB is used for residential buildings (EPF Annual report 2011-12). Figure 3 shows a schematic diagram of commercial OSB production.

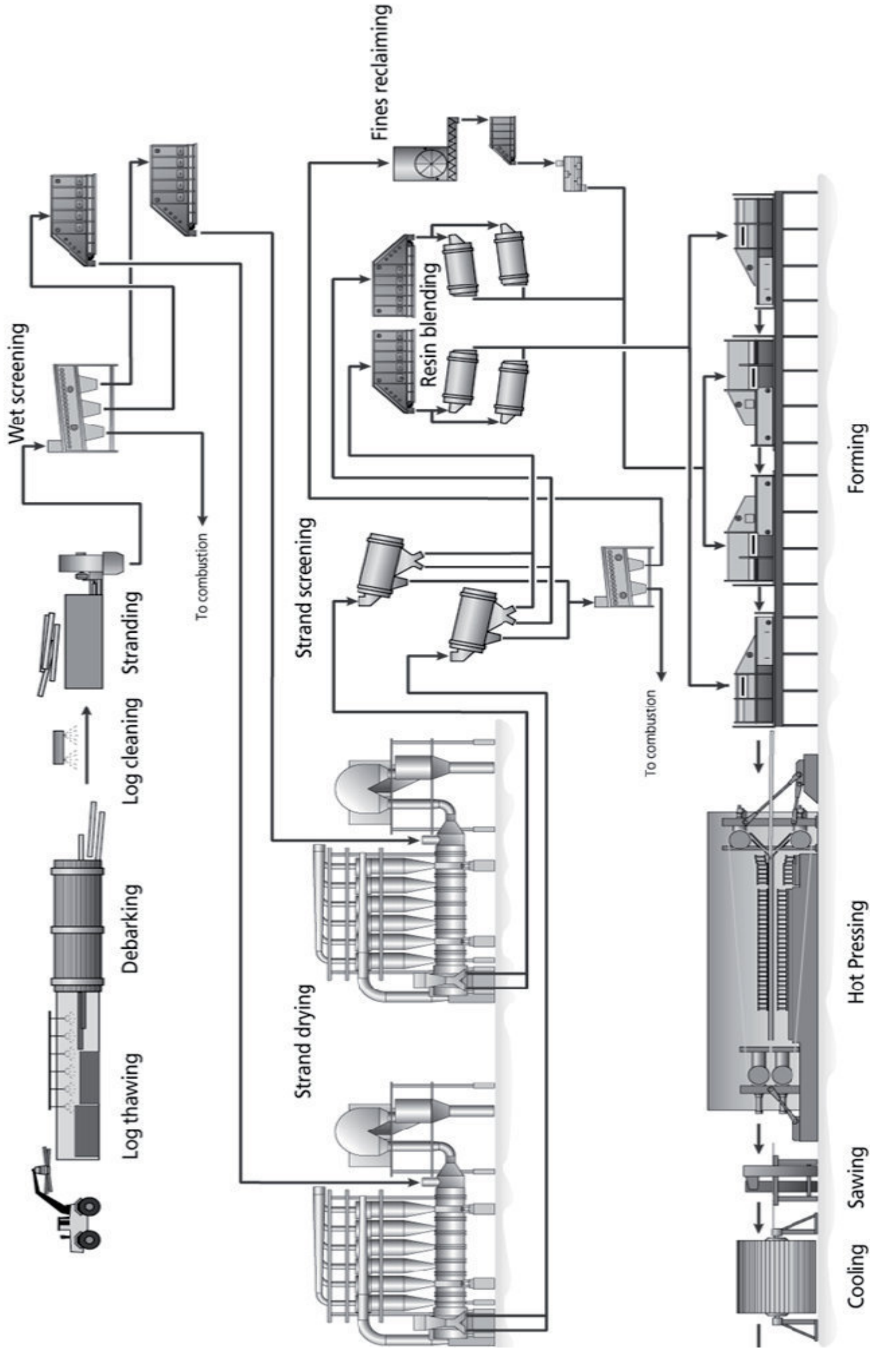


Figure 3. OSB manufacturing process (Metso Panelboard 1998)

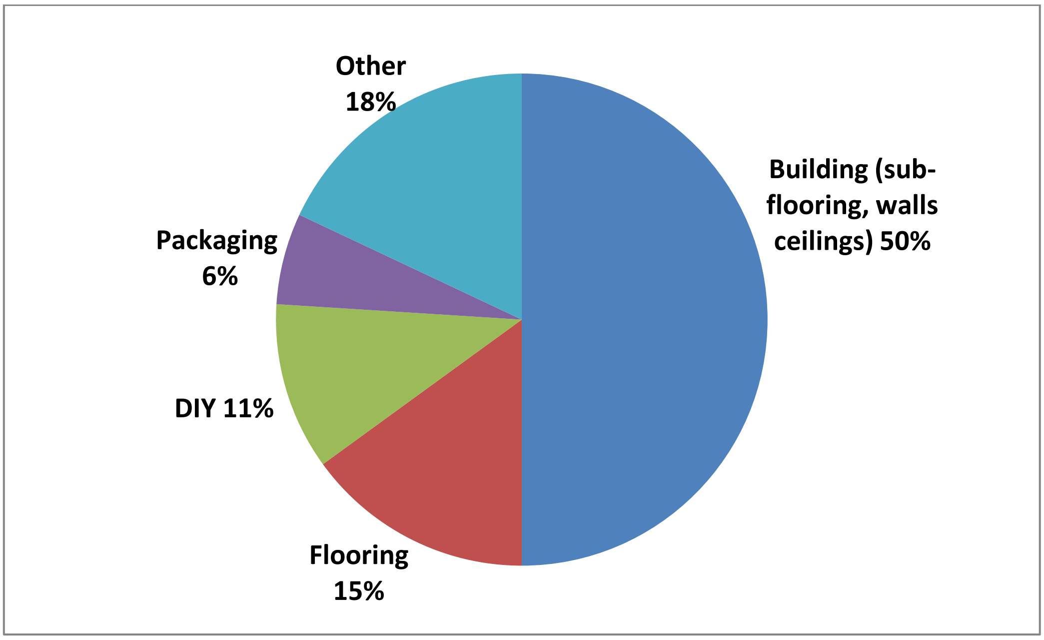


Figure 4. OSB use in Europe (EPF Annual report 2011-12)

2.2 Raw Material

2.2.1 Forest Situation in Europe and Germany

Forests cover over 41 % of the land in Europe, representing 177.8 million ha (Barbu 2012, MCPFE Liaison Unit Warsaw, UNECE, FAO 2007). The largest forest area is located in the Russian Federation, making up 81 % of Europe's forests. There are 1.42 hectares of forest per capita in Europe (MCPFE 2003).

Inside the EU27, Sweden and Finland (each 15 %), followed by France and Spain (each 11 %), Germany (with 8 %), and Poland and Italy 6 % (each). The forest ratio per capita of EU27 is 0.35 ha but Scandinavian countries are the leaders: Finland 4.5 ha, Sweden 3.5 ha compared to Spain 0.6 ha/ and France 0.3 ha (Barbu 2012).

Whereas in the northern European countries (Norway, Sweden, Finland) hardwoods cover only 10–40 % of the total forested area, in central and southern Europe hardwoods cover about one third (Czech Republic and Slovakia 36%), and in some southeast European countries more than one half (Bulgaria 74%, Romania 76%) of the forested area (Chalupa 1987).

Forests cover about 11 million ha or 31 % of the territory of the Federal Republic of Germany. After agriculture, forestry is the second largest form of land use and the most important recreation space in this country (Roering 2004). Softwood species 57.5 % of the forest area, while hardwoods species are covering 42.5 % in Germany. Norway spruce (*Picea abies*) is the most important tree species in German forests. The most eminent deciduous forest tree species is the European Beech *(Fagus sylvatica)* (Roering 2004). Figure 4 shows forest situation in Germany.

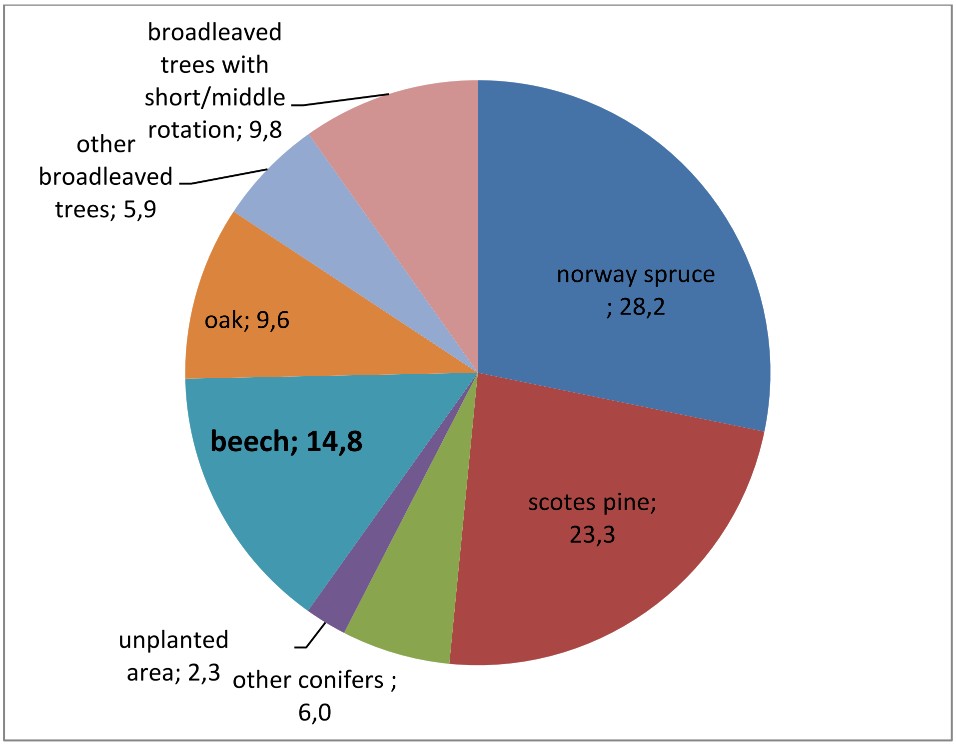


Figure 5. Hardwood and softwood tree species in Germany (DeutscherForstwirtschaftsrat, DFWR)

2.2.2 Species Availability

In general, supplying proper and sufficient raw materials for wood based panels is not limited only to OSB. With increasing demand for using this kind of materials, in particular OSB for the building sector, finding good raw materials that could have the same or even better properties compared to conventional raw materials, and also, availability of these materials are the main concerns of OSB producers. Previous research (Suzuki & Miyagawa 2003; Hiziroglu 2009; Barbuta et al. 2012) showed the main reason of increasing popularity of OSB compared to plywood was the shortage of suitable raw materials and production costs of plywood. Therefore, supplying raw materials is not a new topic and wood based panels have faced this concern for a long time.

Almost all OSB producers in Europe are using softwood species as raw materials like pine and spruce. As mentioned before, increasing demand for using OSB led to increased pressure on softwood species.

On the other hand, today, with increasing warnings from environmental institutes and organizations, it seems finding an efficient way being difficult more and more. Increasing attention to forest preservation, stricter regulations on VOC emissions, concerns about reducing CO_2, and also human health standards for end-used products led scientists and manufacturers to try to develop new technologies and look for alternative raw materials for this huge market in the future. Therefore, VOC emissions of softwood and in this case, pine species would be the other concern of using pine for OSB in Europe.

Based on these two important limitations (availability and VOC emissions), using European beech and poplar as two important hardwood species that are available in almost all European countries and also because of lower extractives compared to pine that results lower VOC emission were studied.

2.2.2.1 Beech Availability and Properties

Fagus Sylvatica L. is the major genus of beech species in Europe. European beech (*Fagus sylvatica* L.) normally grows to 30–35 m tall. Beech trees can live for 250 years or more, but are normally harvested at 80–120 years of age. Germany presently has 15 % of the forest area covered with beech with increasing area and volume (Janssen, 2008).

Beech is relatively resistant to most diseases. It does not suffer from massive predations by pests that lead to a total dieback of stands. Beech wood is homogeneous with fine pores and conspicuous wood rays. Beech is widely distributed in Central and Western Europe. In the northern part of its range beech grows at low elevations while in the southern part it is found at altitudes above 1000 m sea level (Wuehlisch 2008).

Beech wood is from the category of deciduous wood species with diffuse-porous wood structure, i.e. there are only micro vessels (dimensions of 8–45–85 μm; Wagenführ 2000).

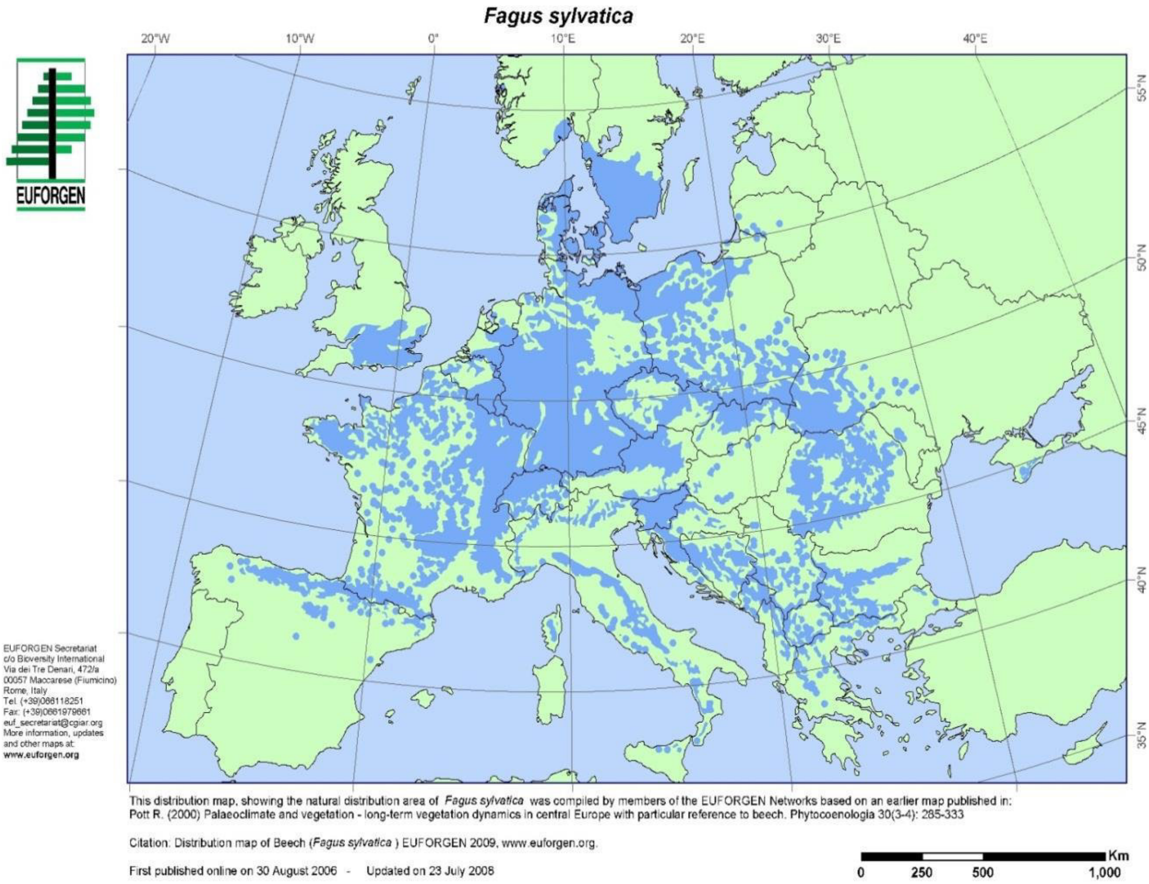


Figure 6. Beech forest distribution in Europe (Citation: Distribution map of Beech (*Fagus sylvatica*) EUFORGEN 2009, www.euforgen.org.)

Table 3. Physical and mechanical properties of beech, poplar, and pine (Source: Kollmann 1951)

Properties		Scots Pine	Beech	Poplar
Average Density		520 kg/m³	720 kg/m³	440 kg/m³
MOR		100 MPa	125 MPa	59 MPa
MOE		12 GPa	16 GPa	8.3 GPa
Shrinkage*	**Radial**	5.2%	5.7%	4.8%
	Tangential	8.3%	11.6%	8.3%
	T/R Ratio	1.6	2	1.7

(* Shrinkage data from http://www.wood-database.com)

Some other anatomical properties of beech are: In transversal section, diffuse-porous to semi-ring-porous. Very numerous solitary and clustered pores in the earlywood, more often solitary in latewood. Earlywood pores sometimes with gum tyloses or gum inclusions. Thick-walled fibres. Apotracheal parenchyma diffuses as well in small, sparse, tangential to oblique bands or aggregates. Large rays generally distended along growth ring boundaries. In radial section: Simple perforation plates and occasional scalariform with up to 20 bars. Rarely with very fine spiral thickenings. Rays homogeneous to slightly heterogeneous with square marginal cells. Presence of transition forms from bordered pits to scalariform perforations occurs frequently. Ground tissue composed of fibre-tracheids. In tangential section: uniseriate to multiseriate rays (up to 0.5 mm wide, 20 cells and 3 to 5 mm high). Frequent sclerotic cells in the center of large rays.

2.2.2.2 Poplar Availability and Properties

Populous tremula L is a widespread colonizing pioneer species. It is a deciduous tree growing to 40 m height with a trunk attaining over one meter in diameter (Wühlisch 2009).

Poplar is a fast growing tree, economically important for wood production for several industrial purposes. In Europe, poplar plantations cover a 940,200 hectares - of which 236,000 are in France, 125,000 in Turkey, 118,500 in Italy, 100,000 in Germany, 98,500 in Spain, 109,300 in Hungary and 55,300 in Romania; France, Hungary and Belgium are also the most important countries exporting poplar round wood while Italy is the major importer (Nervo et al. 2011). Figure 8 shows the poplar forest area in EU. Poplar tree in transversal section seems diffused to semi-ring- porous. Pores solitary or in radial groups or in radial rows of 2 to 3 multiples. Growth ring boundaries are more or less distinct, depending on pore size transition from earlywood to latewood.

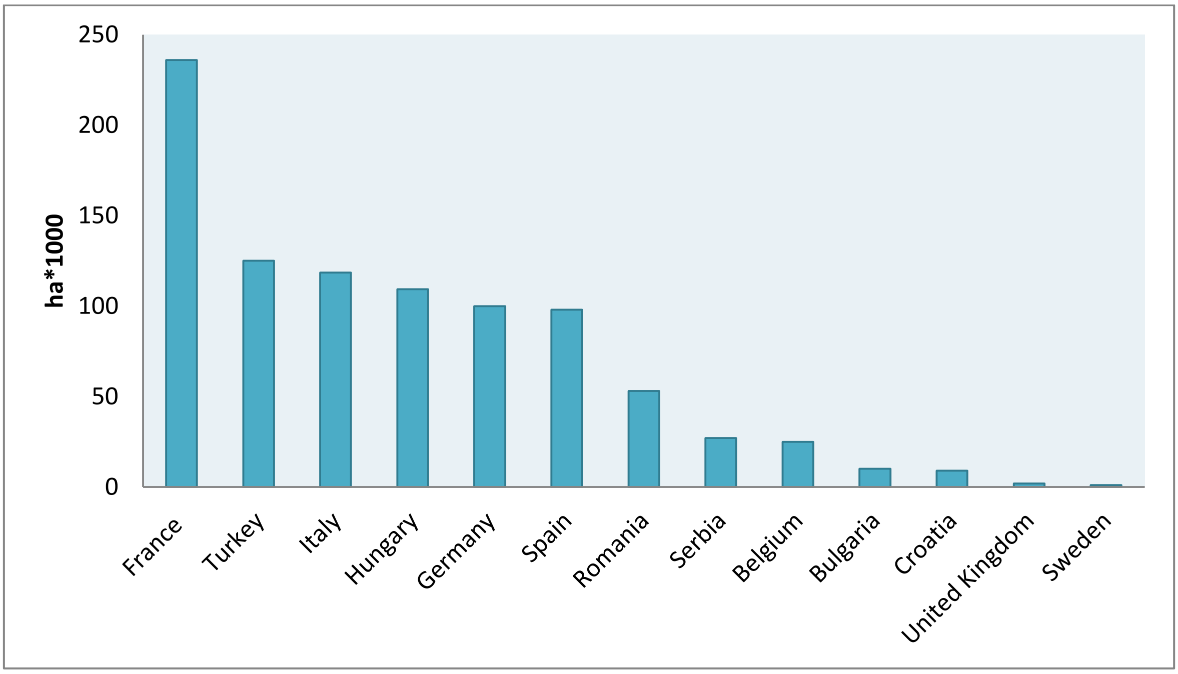


Figure 7. Poplar plantation in Europe (Coaloa & Nevro 2011)

Poplar in anatomical structure shows: In radial section, homogeneous rays, rare with square marginal cells. Simple perforation plates. Extremely large, simple ray-vessel pits. Libriform fibres present, fibre-tracheids absent. In tangential section: Rays uniseriate, ray cells axial oval. Average ray height: 10 to 30 cells. Some other properties are given in Table 3.

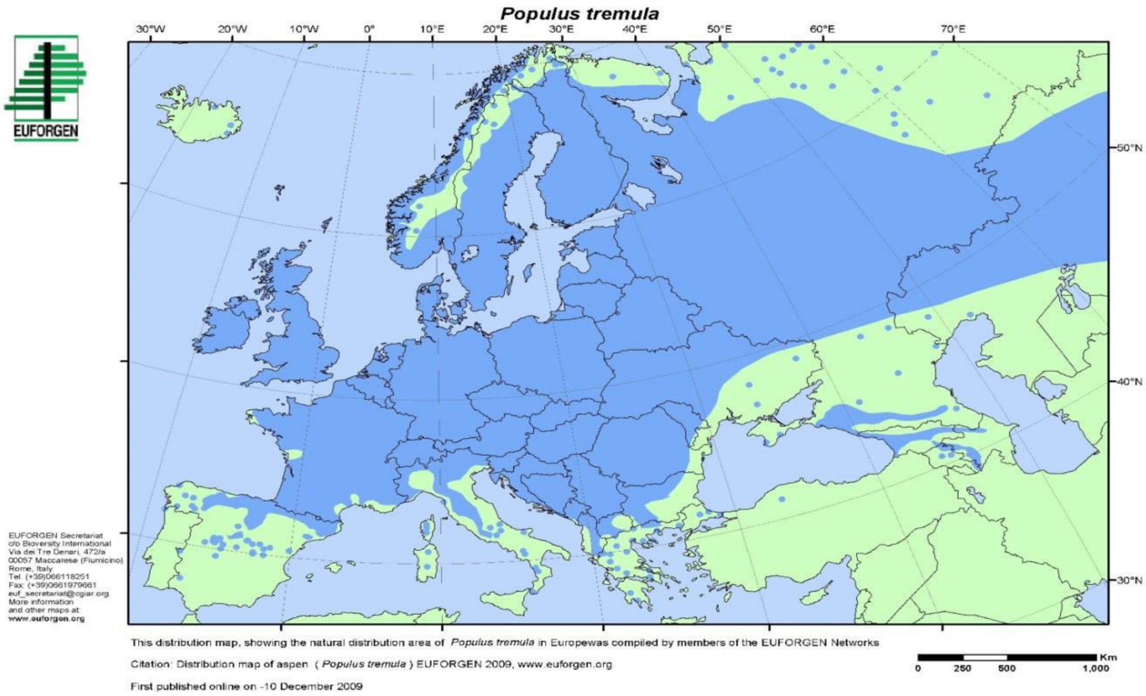


Figure 8. Poplar forest distribution in Europe (Citation: Distribution map of poplar (*Populous tremula*) EUFORGEN 2009, www.euforgen.org).

2.3 Influence of Strand Geometry (Normal and Fine Strands)

Iwata (1995) worked on fine-OSB in Japan and reported that OSB with very thin strands had high performance and could be used as a substitute for lauan plywood. Suzuki & Takeda (2006) determined the effect of strand length and orientation on strength properties of sugi-OSB. He found bending properties were strongly affected by both the strand length and layer structure of the sugi strands. Sumardi et al. (2008) studied the effect of strand length on some properties of bamboo strandboards and they also mentioned the length of bamboo strands has a positive effect on strand alignment. However, an increase in strand length over 120 mm does not cause a significant increase in bending strength or modulus of elasticity and static properties (Barnes 2000).

Beck et al. (2009) worked on the effect of strand geometry and wood species on strandboard mechanical properties. Their results showed that longer and thinner strands resulted in higher MOR and MOE. Slenderness ratio had a significant effect on bending properties. A higher slenderness ratio improved MOR and MOE values.

Strand width has a much smaller role on OSB properties compared to length and thickness. Schwab et al. 2007 found that width does not significantly influence the tensile strength of OSB. Hill (2006) worked on wood modification and mentioned thickness has important role for heat transfer.

According to the Wood Handbook, to qualify as OSB, the strand length to width ratio, or aspect ratio, must be at least 3 (Forest Products Laboratory 1999).

Fine materials have a cost effective influence on production cost. Normally, the significant amount of fines is used in core layer of commercial OSB. Although increasing amount of fine materials leads to reduce mechanical properties (Wu 2003, Han et al. 2006). Specific amounts of fine content vary from one OSB mill to another, but Coil 2005 mentioned some manufactures blend furnish containing up to 15 % or 20 % fines.

There are several parameters which affect the production of fines material during stranding. Some effects are related to logs and wood characteristics such as density, moisture and length of logs, and some others related to the flaking process.

The first factor is related to species. With the same knife geometry and rotation speed of the flaker different sized strands were produced due to the anatomical and structural characteristics of each species.

Other factor is the temperature of logs before flaking. Stiglbauer et al. 2006, determined the influence of knife angle and ambient temperature on fines generation from flakers and recommended wood temperature above 20 °C, and sharpness angle of 26 degrees to generate fewer fines.

Knife angle and the rotation speed of the knives are two other important factors that effects on fines generating. Fine generation can be significantly reduced at OSB flaker by adjusting sharpness angles of flaker (Stiglbauer et al. 2006).

2.4 Panel Density

As for solid wood and all wood based panels, density has a very important effect on most properties, especially strength. Density is the main factor in determining which species are used to manufacture OSB (Maloney 1993).

Density in wood composites is often considered to be a key indicator of board properties (Strickler 1959; Plath and Schnitzler 1974; Steiner et al. 1978). Some of the physical and mechanical properties which are influenced by density include: bending modulus of elasticity (MOE) (Rice and Carey 1978; Xu and Suchsland 1998), modulus of rupture (MOR) (Rice and Carey 1978, Hse 1975; Wong et al. 1998; Kwon and Geimer 1998), tension strength perpendicular to panel surfaces (Heebink et al. 1972; Plath and Schnitzler 1974; Steiner et al. 1978; Wong et al. 1998), shear strength (Shen and Carroll 1969, 1970), thickness swell and water absorption (Rice and Carey 1978; Winistorfer and Wang 1999; Winistorfer and Xu 1996, Xu and Winistorfer, 1995a,b), and linear expansion (Suzuki and Miyamoto 1998; Kelly 1977).

Density for OSB can vary between 0.5 and 0.7 g/cm^3 in commercial production but higher densities are possible. Main factors for density are the density of wood species used and the compression during hot pressing.

Increasing panel density has a positive effect on mechanical properties for all wood based panels (Chen et al. 2010, Sumardi et al. 2007, Han et al. 2006). However, in some pervious research, the negative effect of panel density on thickness swelling and water absorption were observed but it is not a common phenomenon for all panel types and research outcomes (Chen et al. 2010). Lee and Stephens (1988) evaluated seven types of composite boards, including OSB, and found that edgewise shear strength was linearly related to density for most board types. In a study on layer thickness swell (TS), Xu and Winistorfer (1995) demonstrated that the layer TS was positively linearly correlated to layer density. Wang et al. (2003) compared properties of commercial aspen, pine, and mixed hardwood OSB products. They observed that layer TS generally matched well with vertical density profile (VDP).

Brochmann et al. (2004) reported that density was highly significant in determining TS values of OSB, and density accounted for a large amount of variability among IB tests.

Jin et al. (2009) tested randomly oriented strandboards with both uniform and conventional VDP. Their results indicated that IB, MOR, MOE, and WA were well correlated with board density, whereas the relationship between TS and density was less certain. Canadido et al. 1990 noticed that the effect of board density on the orthotropic properties of boards can be recognized at a strand length of 50 mm wherein there is a great degree of strand orientation.

2.5 Densification

As already mentioned in chapter 2.4, density has an important influence on physical and mechanical properties. One process to improve mechanical as well as physical properties is densification. Previous research showed densification process has a positive effect on many properties (Navi and Heger 2004; Kamke 2006; Fang et al. 2011; Laleicke 2012).

The concept of wood densification has been known since 1900, when the first patented densification procedures appeared (Kollmann/ Kuenzi/ Stamm 1975). Kunesh (1968) observed that in radial compression of solid wood, failure first starts with the buckling of wood rays in the earlywood layer and results in progressive failure by buckling of the rays throughout the specimen. Bodig (1965) also found that initial failure occurs in the earlywood layer. Geimer et al. (1985) analyzed damage to the flakes of Douglas -fir flakeboard caused by hot-pressing. He observed the fractures and plastic hinges in the buckled cell walls of some flakes, as well as pure elastic buckling in others.

There are several factors which have significant effects on wood densification such as temperature, time, pressure, moisture, anatomical direction, and species. Cloutier et al. (2008) worked on densification of wood veneers under the effect of heat, steam and pressure. They noted that wood densification under these factors could be an efficient way to increase wood density which results in a stable material in service. They named this process: thermohydromechanical (THM) densification. Fang et al. (2011) also worked on densification of wood veneers with heat and steam. They applied different temperatures of 140, 160, 180, 200, and 220 °C for two light density species, aspen and hybrid poplar. The results showed that densified veneers markedly reduced hygroscopicity: the higher densification temperature, the lower wood hygroscopicity.

Kutnar et al. (2008) examined the morphology and density profile of viscoelastic thermal compression (VTC) wood in relation to the degree of compression. The VTC process increases the density of wood by softening the cell walls prior to compression.

Haller and Wehsener (2004) compressed sawn spruce wood perpendicular to grain to 50% of its original volume. Results showed that the mechanical characteristics are influenced by wood anatomy, anisotropy and moisture content and that strength and stiffness are proportional to the increase of density. Strength, color, as well as swelling, depend on the parameters of the process especially temperature and duration of heating.

2.6 Permeability

Previous research projects such as Haas et al. 1998, Hood 2004 and Dai et al. 2005 indicate that the permeability of particleboard and OSB is affected by the size of the wood particle or strand lengths, width, thickness and also density. Fakhri et al. 2006 measured and modeled the effect of fines content on the transverse permeability of OSB panels and showed that the permeability of the core of commercial OSB is lower and much more variable than that of particleboard or MDF despite being of lower density. Therefore, using and also increasing the fine materials content in the core layer increases the permeability that results in a decrease of pressing time.

The permeability of wood composite panels is also relevant to preservative treatment of the composite (Muin et al. 2003) and moisture absorption/desorption in service (Beldi and Szabo 1986; Sekino 1994). Permeability also critically affects heat and mass transfer processes during the hot-pressing of composite mats (Zombori et al. 2003; Dai and Yu 2004).

Studies including Hata (1993), Haas (1998), Haas et al. (1998), D'Onofrio (1994), Hood (2004), and Dai et al. (2005) have focused on measuring mat permeability to aid the development of hot-pressing models. These studies show that the permeability of particleboard and OSB mats is strongly influenced by wood element length, width, thickness, and mat density. The thermal conductivity and permeability of the mat in the transverse and in-plane directions control the vapor transport processes during hot-pressing, influencing the heating rate of the core, resin cure, board densification, and gas venting (Zombori et al. 2004; Pichelin et al. 2001).

The mat conditions such as temperature, moisture content, and gas pressure were shown to be closely linked to basic mat properties including thermal conductivity and permeability (Dai and Yu 2004).

Hood (2004) and Hood et al. (2005) examined the effects of flake thickness and mat density of OSB on gas permeability through transverse and in-plane directions of the mats. No adhesive was used in the formation of the mats with the exception of the highest density (800 kg/m^3) panels. Both transverse and in-plane permeability decreased rapidly as the compaction ratio increased; transverse and in-plane permeability was higher for mats composed of thicker flakes.

Zahng and Smith (2009) worked on the effects of mat density and flow direction. The authors mentioned careful control of mat permeability and the associated changes in void structure during the press cycle should reduce the likelihood of blown panels and increase the overall throughput and profitability of the plant.

2.7 Resin

2.7.1 Methylene Diphenyl di-isocyanate (MDI)

Isocyanate resins were developed during the 1930's and 1940's and soon became known as adhesives that can bond ''anything to anything'' (Marra, 1992). Formaldehyde based resin like urea formaldehyde (UF), melamine urea formaldehyde (MUF), and phenol formaldehyde (PF) are the main adhesives which are used in wood based panels like Particle Board, MDF and OSB. But because of some advantages of methylene diphenyl di-isocyanate (pMDI) resin compared to common resins, the increasing trend for using this kind of adhesive were observed in recent years. Roll (1990) reported that MDI is more suitable for cellulosic material, spread out spontaneously on a wood surface, and has self-activated distribution characteristics superior to those of PF resin.

pMDI was first used in the German particleboard industries in the early 1970s to produce boards for the building sector. Since then, it is widely used for OSB worldwide and MDF mills in Europe and a few MDF mills in North America. First produced commercially in the early 1960s, the worldwide production of MDI now exceeds 1,500,000 tons annually (Papadopoulos et al. 2002).

MDI and pMDI are produced from aniline, formaldehyde, and a large number of other chemicals, including MDI and benzene.

Using pMDI for the core layer is more common but usage of this resin for both face and core layer is more prevalent in Europe than North America. Some advantages of pMDI are: No formaldehyde emission from the resin, good weathering resistance and high line speeds (press factor 4-8 s/mm).

The disadvantages are: high costs, the need to use a release agent on the steel belt or mat surface and controlled air sucking and air cleaning in the press and cooling star area. Table 4 shows some advantages of MDI compared to conventional resins such as UF, MUF or PF.

Another argument is that MDI resins produce chemical bonds between wood and resin, whereas formaldehyde-based resins only produce semichemical and mechanical bonds.

However, MDI bonds by forming a diffusion interphase in which the resin spreads over the surface of the wood and penetrates into cracks, cell lumen and even cell walls.

Table 4. The advantages of MDI (Source: Huntsman)

Advantages of using MDI compared to traditional resins
Increased mill productivity (compared to PF)
Increased panel's physical properties of the boards
Reduced blender cleaning
Ease of adding biocides or fire retardants
Smooth, light and more natural panel's surface
Lower dosage
Fast curing
Cost-effective binding (compared on cost/m^3)
Improved moisture resistance
Low thickness swelling
Better dimension stability

Penetration depths of up to 1mm are readily achieved, which is well beyond the three cell depth commonly assumed to be needed for wood resins to provide adequate adhesive strength. In the diffusion interphase, the MDI effectively becomes one with the wood and this, along with the penetration and the spread, is responsible for the high quality performance expected from MDI-bonded wood, including the resistance to thickness swell, and the high strengths.

2.7.2 The Chemistry of MDI and pMDI

Like phenol, pMDI is derived from crude oil. pMDI's principal feedstock is benzene. pMDI is a liquid polymer; it is not carried by a solvent, water or otherwise. Yet, polymeric pMDI is stable when compared to the pre-condensate forms of UF and PF: their shelf lives are measured in days, pMDI's in months.

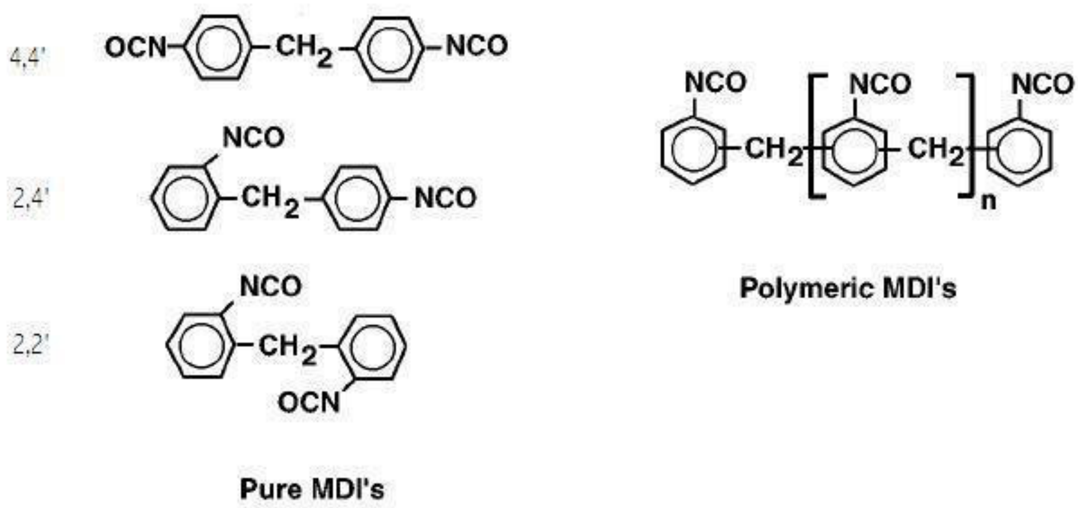


Figure 9. Pure MDI (Dow ISONATE™ and PAPI™ Pure, Modified and Polymeric MDI Handling & Storage Guide – Oct 2009)

Pure MDI may be combined with polyethers, polyesters or other polyols to produce a wide range of products and materials for coatings, elastomers, adhesives and sealants applications including both high- and low-density microcellular foams, fibers, as well as a variety of thermoplastic polymers suitable for extrusion, injection molding and solution applications. Pure MDI is a typical raw material for the production of prepolymer.

Polymeric MDI products (polymethylene polyphenylisocyanates, sometimes referred to as p-MDI or PMDI) are derived from the classic chemical reaction of carbonyl-chloride with aniline-formaldehyde condensate. Polymeric MDI products are well suited for many industrial, manufacturing and specialty end-use applications.

2.8 Resin Penetration into Wood

Wood- adhesive penetration has been studied for a long time (Frihart 2004). Adhesive chemistry, comprehension of the adhesion process, bond formation, the effect of adhesive on wood species, adhesive bonding and its performance are some topics related to adhesive penetration (Johnson and Kamke 1992; Malmberg 2000; Frihart 2005). Traistaru et al. 2011 worked on penetration of paraloid B72 into poplar wood by cold immersion treatments. Their results show the influence of concentration, time and solvent type on the efficiency of the consolidation treatment. The experiment outlined that the longer the treating time, the higher the solution absorption and the consolidate retention.

The degree of resin penetration mostly depends on several factors such as the wood characteristics, resin types and processing parameters (Gavrilovic-Grmusa et al. 2008). Radial penetration of UF adhesives into beech was the topic of Gavrilovic-Grmusa et al. 2008.They applied UF adhesive with different levels of polycondensation and measured the UF penetration by epi-fluorescence microscope. Their results showed depth of radial penetration of prepared urea-formaldehyde adhesives of different viscosity in the beech wood tissue, decreases with raising adhesive viscosity (degree of polycondensation). They also noted the effect of adhesive penetration could be expressed by partly filled or fully filled anatomic vessels in the interphase region.

The permeability, surface energy, and direction (tangential, radial, and longitudinal) are wood-related factors controlling wood adhesive penetration (Kamke and Lee 2004). Sernek et al. (1999) observed lower penetration by UF resin in radial direction of beech than that in tangential direction. This was attributed to the large vessel structure and more radial pits.
Regarding the influence of resin type several parameters have an effect on resin penetration such as: molecular weight distribution, viscosity, solid contents, and surface tension of liquid phase. Hse (1971) reported a correlation between penetration and contact angle for PF and southern pine plywood. The author evaluated 36 formulations in regard to contact angle, cure time, heat of reaction, plywood shear strength, percent wood failure, bondline thickness, and cure shrinkage. Penetration was not measured, but assumed to be inversely proportional to bondline thickness (thickness of cured adhesive between the veneers). Penetration increased with increasing caustic content. There were no clear trends observed for penetration in relation to adhesive solids content or formaldehyde-phenol mole ratio.

Frazier et al. (1996) noted that low molecular weight of MDI resin would promote penetration into wood cell walls with true molecular mixing occurring.

They further hypothesized that the MDI forms an interpenetrating network (IPN) of polyurea and biuret linkages within the cell wall. Swelling of the cell wall by MDI was also observed by Frazier (2003).

Variation of resin penetration among different types of resin becomes larger when the difference in the molecular weight (MW) of resin is considered (Nearn 1974; Johnson and Kamke 1994; Stephen and Kutscha 1987; Gollob et al.1985).

Open assembly time, pressing time, temperature, and consolidation pressure are different processing parameters which impact resin penetration. For example, White (1977) studied the influence of consolidation pressure on penetration and subsequent fracture toughness of southern pine blocks bonded with resorcinol-formaldehyde. Increasing consolidation pressure from 3 to 1000 kPa increased penetration into earlywood, but had an erratic effect on latewood. The author suspected that the low permeability of the latewood contributed to adhesive squeezing out of the bondline during consolidation.

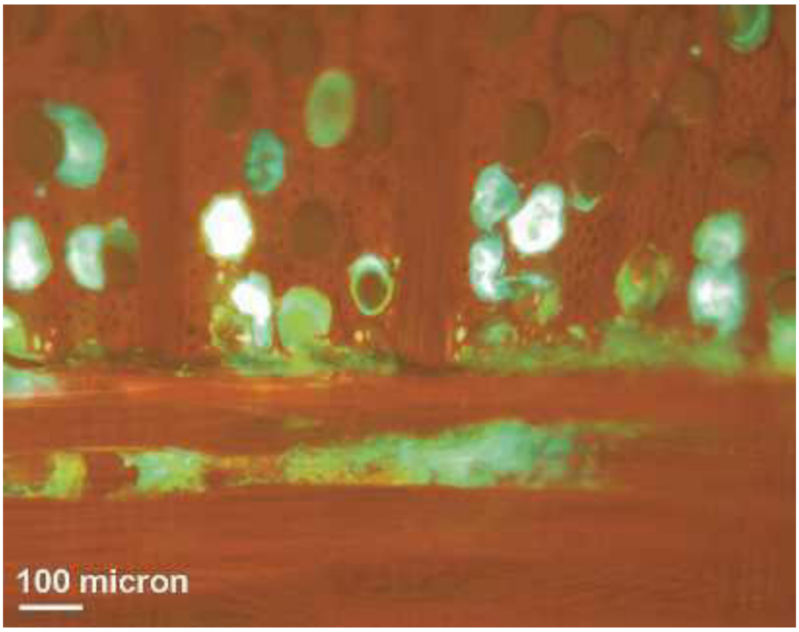


Figure10. Photomicrograph of a UF bondline in beech as viewed using epi-fluorescence and stained with 0.5 % safranin O. Upper lamina is transverse surface, lower lamina is radial surface. Bright areas are resin. Filter set 360-nm/400- nm/420-nm (Sernek et al. 1999)

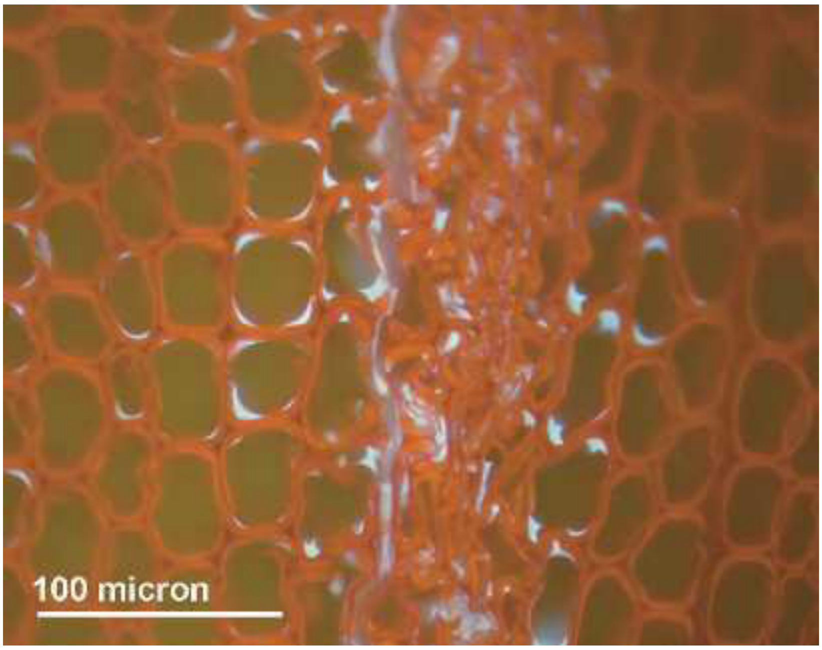


Figure 11. Photomicrograph of a MDI bondline in southern pine using epi-fluorescence and stained with 0.5% safranin O. Transverse view of vertical bondline. Bright areas are resin. Filter set 360-nm / 400-nm / 420-nm (Kamke 2004)

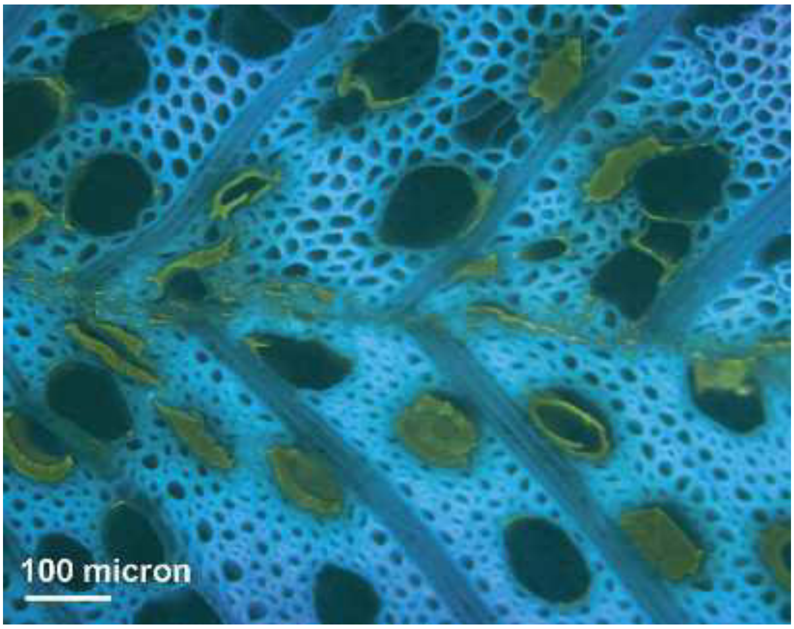


Figure 12. Photomicrograph of a PF bondline in yellow poplar using epi-fluorescence and stained with 0.5% toluidine blue O. Transverse view of horizontal bondline. Brown areas are resin. Filter set 360-nm/400-nm/420-nm (Zhang 2002)

2.9 Volatile organic compounds (VOC)

It is well known that the main use of wood-based panels and also OSB is in interior application. In order to control and reduce potential indoor emission sources, several national and European initiatives have been launched, including the German Committee for Health-related Evaluation of Building Products (AgBB: "Ausschuss zur gesundheitlichen Bewertung von Bauprodukten"). Its main task is the establishment of a uniform health-related assessment scheme (AgBB 2004). Previous studies (Tshudy 1995, Salthammer 1999) showed that 96 percent of the volatile organic compounds (VOCs) found in buildings result from the materials used to build and furnish the buildings.

Terpenes and aldehydes are often identified as major sources of VOCs in indoor air (Hodgsen et al. 2002, Makowski and Ohlmeyer 2005).

Beside possible influences during the manufacturing process, e.g. the conditions of drying and hot pressing, hot stacking may alter VOC emissions from wood based panels.

However, there is a real lack of information on nature and concentration level of the pollutants emitted by wood products. Several data on formaldehyde emission from wood based panels were available following regulations in certain countries. But VOC emission results are more difficult to obtain and even when data are available, they were not easily comparable due to lack of uniformity in the different national testing methods and the type of tested material (ECA-IAQ 1993).

In general VOC emissions are affected by several factors such as: wood species, wood or strand drying, strand blending (glue type), hot pressing, cooling and storage. Some of these factors have great influence on VOC like hot pressing.

Terpene and aldehyde emissions were affected by the pressing (time) factors in different ways: terpene emissions are lowered with elevated pressing times, whereas the formation of volatile aldehydes is accelerated. Drying temperature mainly affects the dynamics of aldehyde formation, with a clear rise and fall in aldehyde concentration after drying at elevated temperatures (170 °C > 200 °C) (Makowski & Ohlmeyer 2006).

It is possible that drying of wood changes the emission of VOCs and aldehydes from wood since the release of these compounds during drying has been reported (Fritz e al. 2004; McDonald et al. 2002; Milota 2003).

The VOCs emitted from wood particles containing no adhesive resin consist of wood extractives, thermal and oxidative degradation products of wood components, and chemical reaction products of wood extractives (Word 1983, 1986). The VOCs emitted from wood adhesives are formaldehyde, methanol, phenol, and methylene diisocyanate (Word 1986, Carlson et al. 1995, Wolcott et al. 1996, Wang et al. 1999).

3 Research Concepts & Experimental Design of the Study

As mentioned in chapter 1 & 2, the aim of this study is to develop new ideas for the substitution of current raw materials for OSB in Europe. Chapter 2, gave an overview of the history of OSB and the increasing importance of this product during last decade for structural application in Europe, the current situation of OSB production and wood species, the limitations of conventional raw materials, the influence of strand geometry and using fines material to decrease production costs, the advantages of MDI resin for OSB, the effect of panel density of properties of OSB, and also densification behavior.

As already mentioned the main goal of this project was to evaluate beech and poplar wood species as alternative raw materials for OSB production. The purpose was to substitute 100 % or to mix current softwood materials with beech and poplar as two widespread hardwoods species. In terms of technology, the attempt was to find the best combination of beech and poplar as the only material for panels or a mixture of both species at different mass ratio and use them in layers to have the same or even better physical and mechanical properties as pine based OSB. Beside these aspects, the goal was to reduce ecological burdens, such as VOC emissions, to provide more eco-friendly boards. Based on overall goals, the experimental design of this project is defined by different factors such as:

a) Raw materials
   - Using hardwoods especially beech and poplar because of their availability in almost all European countries

b) The influence of strand geometry especially fine content on technical properties

c) Board design
   - 100 % beech
   - 100 % poplar
   - Beech in face and poplar in core layer (with different face/ core thickness and density)

- Using fine strands in core layer (with different fine content) for both beech and poplar boards
- A mixture of beech and poplar and also a mixture of beech and pine- a mixture of poplar and pine
- Different densities (650 & 720 kg/m^3)

d) Board fabrication
   - Board dimension 60*55*1.6 cm^3
   - Press factors
     - Temperature 180 °C
     - Time 15 s/ mm
     - Thickness/ distance mode 16 mm
   - Resin
     - 5 % MDI
   - Core layer perpendicular to the surface layers
   - No wax or other additives
   - Replicate 2 boards for each treatment

e) Board properties
   - Vertical density profile
   - Modulus of rupture (MOR)
   - Modulus of elasticity (MOE)
   - Internal bond (IB)
   - Thickness swelling (TS)
   - Water absorption (WA)

f) VOC measurement
   - Beech and poplar as solid wood (at 12 % m.c)
   - Beech and poplar panels (240s and 180 °C)

g) Densification behavior
   - Beech and poplar veneer
   - Two temperature (180 °C & 220 °C)
   - With and without UF resin

In total 72 boards were planned for manufacturing made of pure beech and poplar species (32), fine core materials (24), and a mixture of the species together and with pine strand (16). For VOC measurement, plus two solid wood samples for beech and poplar, 4 boards seem to be sufficient.

Tables 5a to c, show the different combinations and designs of normal, fine and mixed wood species strands OSB. A more detailed description of individual part step follows in chapter 4.

Table 5a. Design of the OSB made from normal strand size (b: beech, p: poplar)

Panel Number	Density (kg/m^3)	Panel Type	Combination
A1	650	beech	100%
B1	720	beech	100%
C1	650	poplar	100%
P1	720	poplar	100%
K1	650	b+p+b	30-40-30%
F1	720	b+p+b	30-40-30%
D1	650	b+p+b	25-50-25%
E1	720	b+p+b	25-50-25%
L1	650	b+p+b	12,5-75-12,5%
G1	720	b+p+b	12,5-75-12,5%
M1	650	p+b+p	30-40-30%
J1	720	p+b+p	30-40-30%
H1	650	p+b+p	25-50-25%
I1	720	p+b+p	25-50-25%
O1	650	p+b+p	12,5-75-12,5%
N1	720	p+b+p	12,5-75-12,5%

Table 5b. Design of OSB panels made from different fine strand amounts (density of all panels 650 kg/m^3)

Panel Number	Panel Type	Core Fine Proportion %
A2	B	10% Fines
B2	B+P+B	
C2	P+B+P	
D2	P	
E2	B	30% Fines
F2	B+P+B	
G2	P+B+P	
H2	P	
I2	B	50% Fines
J2	B+P+B	
K2	P+B+P	
L2	P	

B: beech, P: poplar

Table 5c. Design of the OSB made from mixed strands

Panel Number	Density (kg/m^3)	Panel Type
A3	650	beech+poplar (mix)
B3	720	beech+poplar (mix)
C3	650	beech+pine (mix)
D3	720	beech+pine (mix)
E3	650	poplar+pine (mix)
F3	720	poplar+pine (mix)
G3	650	pine
H3	720	pine

4 Materials and Methods for the Experiment

In this chapter, the preparation of strands and other materials which were necessary for this project are illustrated. Because of using different strand size and different wood species in each specific part, the information given is more detailed.

4.1 Strand Preparation

4.1.1 Log Selection and Preparation

Small diameter beech (15-30 cm) and poplar (20-30 cm) were selected from a location near Hamburg (Reinbek, Vorwerksbusch) and in the forest cut to about 120 cm length (Fig. 13). This length matched with the size of the flaker. After that the logs were carried to the lab and were debarked by hand.

Figure 13. Cutting beech trees in Reinbek 2011

Immediately after unloading the fresh logs from the forest, the debarking operation was started. It is well known that bark has a negative effect on board properties and maximum 10 % of bark was used in wood based panels, especially for particle board (Aaron 1973). All OSB industries use debarked logs (drum debarker) in order to improve board quality and color and reduce fines content. Figure 14 shows the debarking knife and debarked logs.

Figure 14. Knife device for debarking logs (left) and debarked logs (right)

4.1.2 Flaking Process

After debarking, the logs were transported to Pallmann Company, Zweibrüken/ Germany for flaking. A lab knife ring flaker (Fig. 15) was used for flaking the strands.

Based on different project strategies, the normal sized and fine (small) strands were needed. Therefore the distance between knives in the ring flaker was adjusted to produce different strand sizes. The same procedure applied for different species due to different anatomical characterization. Because the same thickness and length were vital to have a proper compression among different board designs and material combinations, all knives were re-adjusted after processing beech in order to produce the same strand dimension from poplar strands.

4.2 Normal Sized Strands

At the beginning of the flaking process [some initial logs were processed] to be sure that the strand dimension was exactly as requested. A number of 10 strands were measured to examine the exact thickness of strands. Figure 15 shows the produced strands behind the flaker.
The set strand geometry was: 12.5 cm in length, 0.7 mm in thickness and 20-40 mm in width.

4.3 Fines Content

The geometry of fine materials was similar to the normal strands. Only length of fine strands was about one third of normal strands (30-40 mm). Figure 16 shows the normal and fine strands of poplar species.

Figure 15. Knife ring flaker (left) and beech strands (right)

Figure 16. Normal (left) and fine (right) poplar strands at 10 % m.c

4.4 Pine Strands

For comparison, strands from pine wood were used. These strands were taken from Koronoply Company in Heiligengrabe, Germany. The strands were 150, 0.7-0.8 and 20-50 mm, in length, thickness and width, respectively. The strands were collected after the dryer and the moisture was between 3 to 5%. The dried strands were loaded into plastic bags to avoid moisture uptake.

It is known that the size distribution of strands prepared in a laboratory process (lab flaker and kiln drying of the strands without moving the strands) and in an industrial process (mill flaker- drum type- and rotary dryer) could be different. But using beech, poplar, and pine in the same flaking/drying process also would result in different strand size distribution. Therefore, pine strands from industry were selected which may give better comparison between industry and lab made panels. Figure 17 shows pine, beech and poplar strands which were used in this research.

Figure 17. Pine (left), poplar (middle) and beech (right) strands at 10 % m.c

4.5 Strand Drying

Immediately after the beech and poplar strands returned to the institute, the drying process was started. Wet strands were put on a box made of wire mesh and then expose to the hot air in a kiln dryer. In each loading approximately 6 kg of strands were put in dryer at a drying temperature of 90 °C. The dryer was adjusted to achieve on 5 % moisture content based on oven-dry weight. To ensure the correct moisture content, several samples were moisture checked by putting in the lab oven for 24h. Figure 18 shows the kiln dryer and loading of beech strands.

Figure 18. Kiln dryer

In this study, the moisture content of strands for surface and core layer was 10 and 5 %, respectively. Because of huge amount of wet strands and necessary to dry them as soon as possible and also difficulty to adjust different levels of moisture content in the dryer, all strands were dried to 5 %. Then, in the time of producing the panels, the surface strands were sprayed with water to increase moisture to 10 %. Then, the strands were packed in the plastic bags for 3 days to ensure that the all parts of strands reach that content moisture.

4.6 Screening of Strands

Because producing fine materials is an inevitable part of the flaking process and also to prevent using these fines in face layers, a lab screen with 2 different meshes (25 mm for oversize strands and 1,6 mm for fine materials) were used after drying. This step was only used for normal strands. Because for panels made with fines in core, the separation between fine and normal strands have already been done during the flaking process.

4.7 Board Manufacturing

4.7.1 Blending of Strands

5% commercial pMDI resin were used for both face and core layers in all panels. Poly methyl diisocyanate is a water resistant resin that is used for exterior application especially at high humidity condition. The characteristics of the resin which was provided by Huntsman / Belgium are listed in Table 6.

Table 6. Physical and mechanical properties of MDI (Source: Huntsman)

Properties	
Physical state	Liquid
Color	Brown
Odor	Slightly musty
Boiling point	>300 °C decomposes
Flash point	Closed cup: 230 °C
	Open cup: 230 °C
Explosion limits	Not explosive
Density	1.23 g/cm^3 (25 °C)
Solubility	Insoluble in water
Partition coefficient	Not applicable. Reacts with water and octanol
Viscosity	Dynamic: 225 mPa.s
Vapor density	8.5

A drum blender (Lödige, Type RM300 D) was applied for blending the strands and resin. Because there was only a small opening at the bottom of the blender, the long strands blocked this opening and unloading of the strands presented a big problem. Therefore the strands were unloaded through the large top opening of the blender. Figure 19 shows the blender.

Regarding the use of fine strands, the normal and fine strands were blended separately to ensure more homogenized resination and also reduce to the risk of absorbing more resin by fine strands. When strands and fines are blended together, the fines tend to have higher resin coverage than strands because of the higher total surface area in the fines (Maloney 1993, Campbell 1997).

Then for panels made of mixed normal and fine materials, these resinated materials were mixed in the blender for some minutes.

Figure 19. Drum blender

4.7.2 Forming the mat

An essential part of making OSB is forming. Unlike particle board and medium density fiberboard (MDF), orientation of strands plays an important role for the properties of the boards. In general, the strands in face layers were oriented more or less parallel to the longer axial and core layer oriented perpendicular to the faces.

In the lab the forming of the panels / the single layers were done manually by using a metal blade alignment device for strand orientation. In case of using fine material for the core layer, the strands were randomly oriented.

Strands were formed in a wooden box (Fig. 20), 60*55 cm^2. Depending on the different designs and combinations and also face-core ratio, the beech and poplar strands were placed in face or core layer.

Figure 20. Forming of OSB mat

For making a mixture of beech and poplar strands and also the mixture including pine, reflecting at 50-50 face core ratio, strands were weighted and put in specific layers.

The thickness of all panels in this study was 16 mm.

Panels made with normal strands and also a mix of different strands was manufactured at two densities (650 and 720 kg/m^3). For panels made with fines in core layer, only boards with 650 kg/m^3 were produced.

4.7.3 Hot Pressing

After forming the mats, a hot laboratory Siempelkamp press was used to press the panels (press plate size: 800 $*$ 600 mm^2). Because of using MDI resin and to prevent sticking of resinated strands to the press plates, a release paper was laid on the metal plates before loading the press with the panels. The press conditions were chosen after initial trails and information from previous research in the literature. The press factors were adjusted to the press temperature of 180 °C and 240s.

Preliminary trails with 220 °C and 10 s/mm press factor showed that this press factor is not feasible because blisters were observed in panels made of pure poplar. That is related to a high gas pressure inside the boards. Because the press program was based on distance-mode, the press pressure was applied at the maximum rate.

Unlike PB and MDF, the strands laid flat-side down and pre-pressing of the mat is not necessary.

After finishing the press cycle all panels were labeled, weighted and also the direction of axial length was marked. Then, 5cm of each edge of panels were trimmed because of lower density.

Figure 21. Feeding the hot press (without top press sheet)

4.7.4 Cutting Panels to Size

A cutting plan was determined to produce the test sample for physical and mechanical properties (Fig. 29). All samples were put in the climate room (65 % RH and 20 °C) for 3 weeks to reach the constant weight. Physical and mechanical properties were determined based on EN standards as shown in Fig.22.

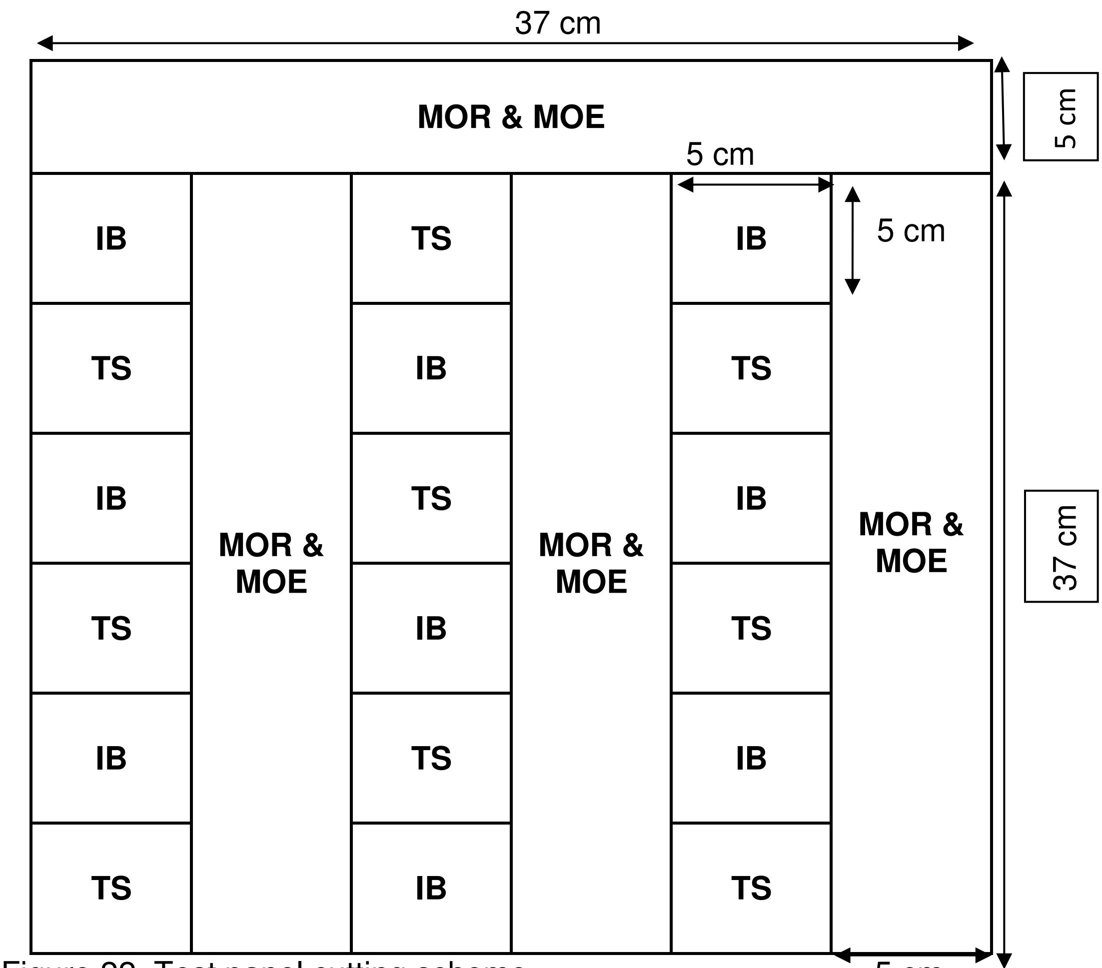


Figure 22. Test panel cutting scheme

Figure 23. Prepared samples for tests

Table 7. Tested physical and mechanical properties and requirement properties according to EN standard

Property	Test method	Type	Requirement [N/mm^2], [%]		
			Board Thickness Range (mm nominal)		
			10 >	> 10 and < 18	18 - 25
Bending Strength Major axis	310	OSB/1	20	18	16
		OSB/2	22	20	18
		OSB/3	22	20	18
		OSB/4	30	28	26
Bending Strength Minor axis	310	OSB/1	10	9	8
		OSB/2	11	10	9
		OSB/3	11	10	9
		OSB/4	16	15	14
Modulus of Elasticity Major axis	310	OSB/1	2500		
		OSB/2	3500		
		OSB/3	3500		
		OSB/4	4800		
Modulus of Elasticity Minor axis	EN 310	OSB/1	1200		
		OSB/2	1400		
		OSB/3	1400		
		OSB/4	1800		
Internal Bond	319	OSB/1	0,3	0,28	0,26
		OSB/2	0,34	0,32	0,3
		OSB/3	0,34	0,32	0,3
		OSB/4	0,5	0,45	0,4
Swelling in thickness 24 hour	317	OSB/1	25		
		OSB/2	20		
		OSB/3	15		
		OSB/4	12		

Modulus of elasticity (MOE), modulus of rupture (MOR), internal bond (IB) strength, thickness swelling (TS) and water absorption (WA) after 24h were determined based on the EN 300 standard. From each panel three samples (370 mm by 50 mm) for bending test were used. For internal bond strength test nine 50 mm by 50 mm specimens were cut from panels. Prior to IB test, three samples were chosen for analyzing density profiles in the thickness direction using X-ray densitometry (Itrax Wood scanner, Cox Analytical System) based on the relationship of X-ray and density. Nine 50 mm by 50 mm by 16 mm were cut for thickness swelling and water absorption (in total 18 samples for each treatments). Average thickness was measured at the middle of each sample. Later, the samples were submerged into water for 24h then specimens were dripped and wiped cleaning of any surface water. The thickness of specimens was measured with digital caliper of 0.01 mm precision. In measurement of MOR and MOE values, a Zwick/Roell Z050 universal test device was used. In testing, the loading mechanism was operated with a velocity of 10 mm/min. before MOR and MOE testing, the length, width, thickness, and weight of each sample were measured to determine the density. The internal bond strength test was performed with a universal testing machine as well (Losenhausenwerk). Figures 24 through 27 show different devices for physical and mechanical machines tests and also X-ray densitometry.

Figure 24. Length, width, and thickness measurement

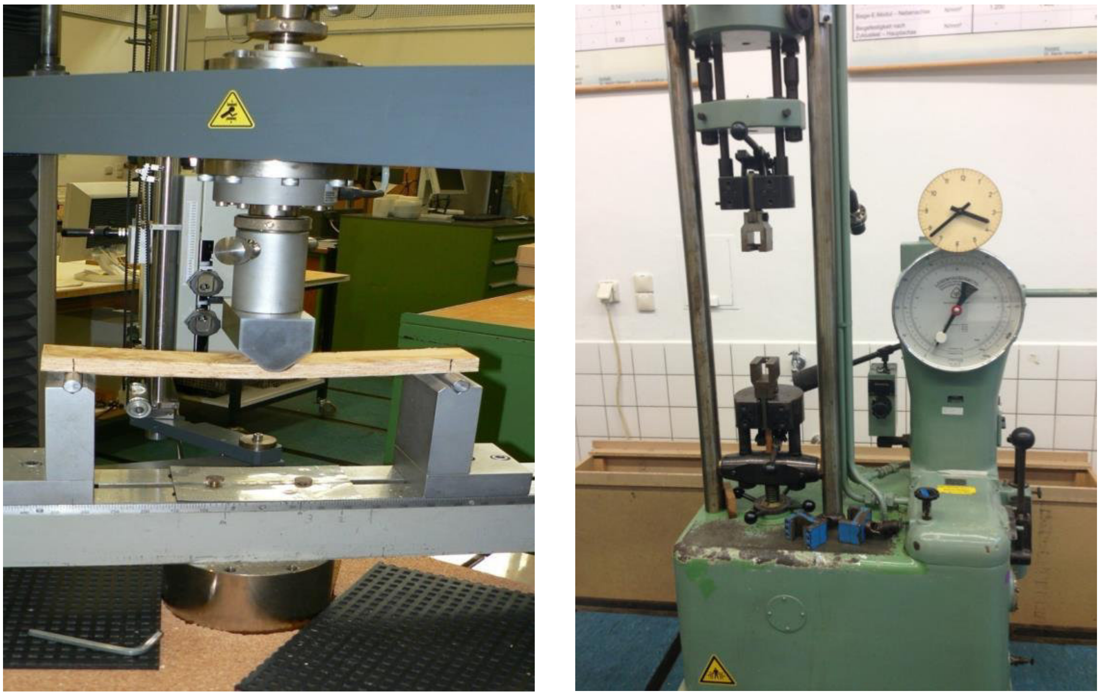


Figure 25. MOR & MOE (left) and IB (right) test

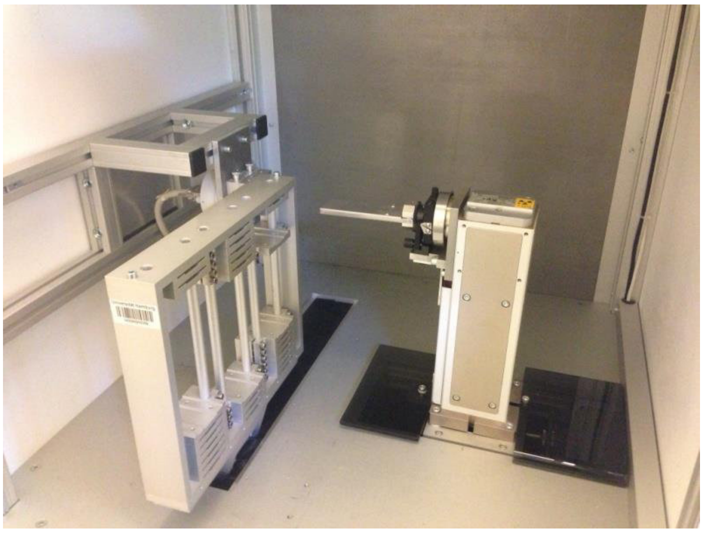


Figure 26. X-ray device for vertical density profile

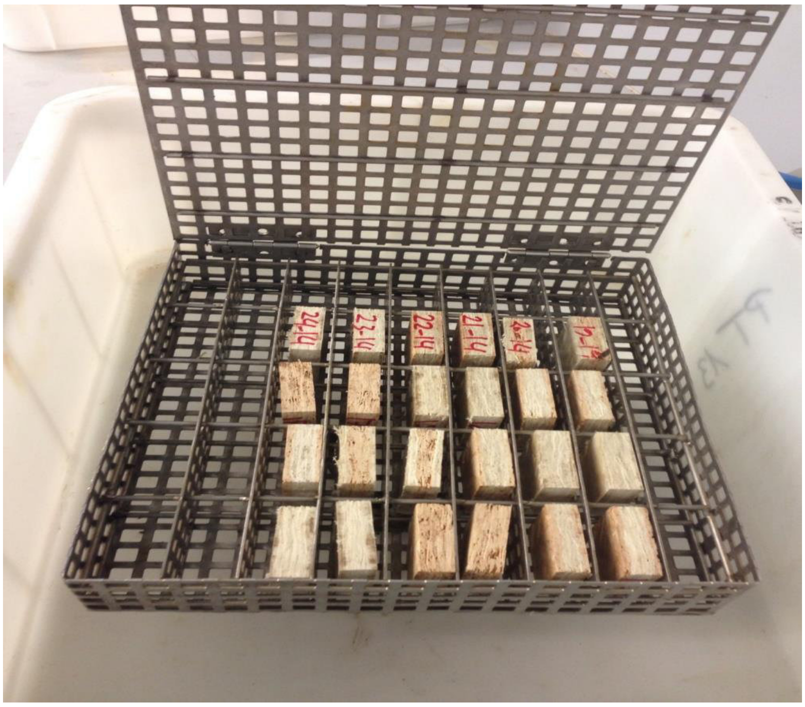


Figure 27. Steel frame for TS and WA measurement

4.8 VOC

For VOC measurement, 3 different groups were tested. A) Two samples of OSB made of beech in surface, B) samples of OSB made of poplar in surface and C) beech and poplar solid wood were chosen (Table 6).

The size of samples which required for VOC measurement was 722 cm^2. For this size, the small panels with 40 to 40 cm at 650 kg/m^3 with 5 % pMDI were produced. After half an hour cooling, all panels were trimmed to 21 to 21 cm^2. Immediately after cutting, the edges of each sample were edge-sealed, overlapping 1 cm, with an aluminum-coated adhesive tape at room conditions before testing. The emitting area was 722 cm^2. Table 8 shows different combinations of samples were prepared for VOC tests.

Table 8. VOC samples

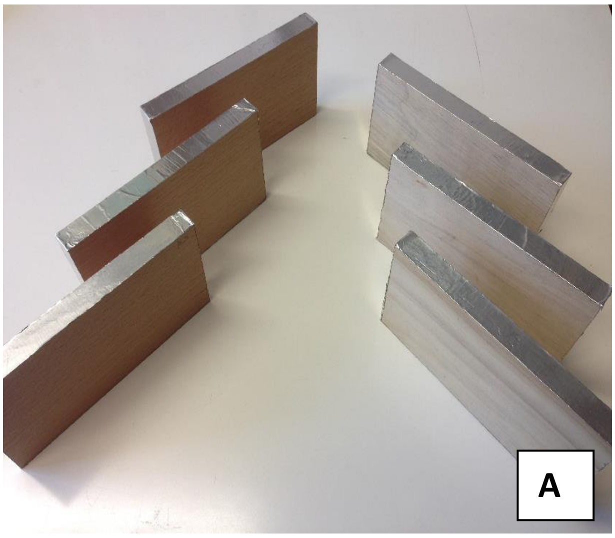
Type	Face / Core		Press conditions
A	normal strand beech	fine beech	180 °C 240s
B	normal strand beech	fine poplar	
C	normal strand poplar	fine beech	
D	normal strand poplar	fine beech	
E	beech solid wood		
F	poplar solid wood		

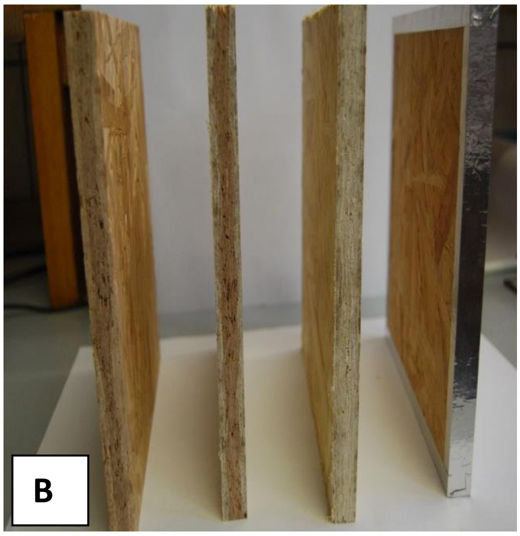
For solid wood samples, because of small log sizes which were not enough for VOC emission test, 3 small pieces were prepared to cover the requirement area for this test. Then all samples were vacuumed in plastic bags. The VOC measurement based on EN standard started less than 20 hours after making panels. Samples were placed into the environmental testing chamber commencing the testing period. The samples remained inside the chamber for the whole duration of testing (periods of 28 days).

Because of the same method was applied compared to Makowski and Ohlmeyer 2005, the VOC measurement method followed their article:

"Sampling and analytical procedures as well as the equipment were in accordance with DIN EN ISO 16000-6:2011. Tests were performed in environmental test chambers (glass desiccators) with a volume of 23 liters. A constant and adjustable airflow (1.200 l min^{-1}) was led through the chamber resulting in 3.1 air exchanges per hour. The loading factor was n = 3.1 m^2 m^{-3} and the resulting area specific airflow rate q = 1.0 m^3 h^{-1} m^{-2}. The airflow was conditioned for a temperature of 23 ± 0.5°C and a relative humidity of 50 ± 3%. Both were measured at the inlet port.

Air samples were collected on Tenax TA (200 mg, 60 … 80 mesh) using an air sample pump with electronic flow controller. A sample flow rate of 100 ± 1 $ml min^{-1}$ was used for a period of 5 to 40 minutes, which equals a total air volume of 0.5 … 4 liters. Before sampling, each tube was spiked with 200 ng toluene dissolved in methanol as internal standard. This semi-quantitative assessment describes the development of the emissions, rather than exact concentrations. Depending on concentrations and properties of the individual compounds results deviate about ± 30 % from actual concentrations."





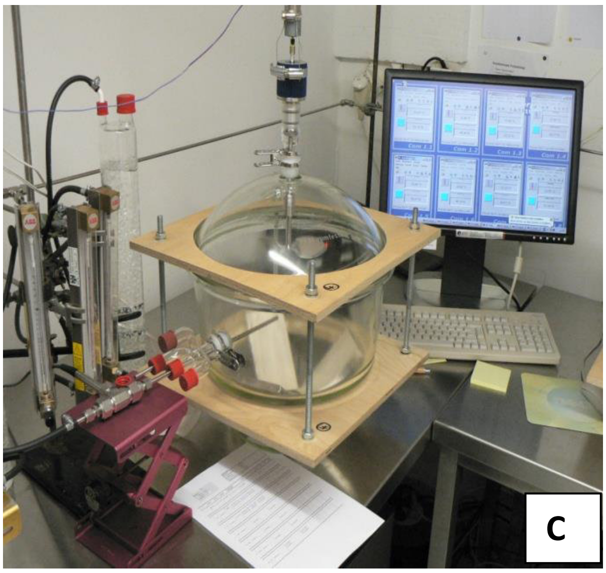


Figure 28. Sample preparation for VOC (A: Solid wood sample, B: OSB Sample) and C: Desiccator

4.9 Densification

Densification behavior of solid wood and veneer strips was the main topic of Laleicke's master thesis (2012) which was a part of this research project to make a model related to strands densification. In this part a short explanation regarding veneer densification and veneer bending which are effects on strand densification during hot pressing was illustrated. More details and information are given by Laleicke 2012.

4.9.1 Compression Veneer Strips

From two beech and poplar logs sliced veneer was processed by the company "Beyer Furniere Pritzwalk". An ongoing review of the stripe width shows a sufficient accuracy of the nominal width of 20 mm. The 2.5 m and 2 m long strips of veneer were bundled and transported in crates back to Hamburg. The final cut into 350 mm long strips was carried out using a table saw.

4.9.2 Mat Geometry and Manufacturing

To achieve standardized design, a wooden frame was made from plywood. In the inner sides 1.5 cm deep slots of even distance were cut using a circular saw. In these slots steel sheets (95 * 20 mm) were put (Fig. 29), which were fixed with an additional veneer strips. The inside dimensions of the frame were 350 * 350 mm^2, and the frame height was 100 mm. The thickness of the laid up veneer mat is significantly higher than the final thickness, because the strips are initially placed loosely over each another (basically the mat consisted of 12 layers). Using veneers of 1 mm, the thickness of each mat was 12 mm. In the arrangement of the veneer strips, two different systems have been selected.

Beside the normal arrangement in which there are 12 strips in each layer (Mat A), a "Woven" design was developed where the veneer strips were bent (Mat B). In this arrangement, every second strip is omitted.

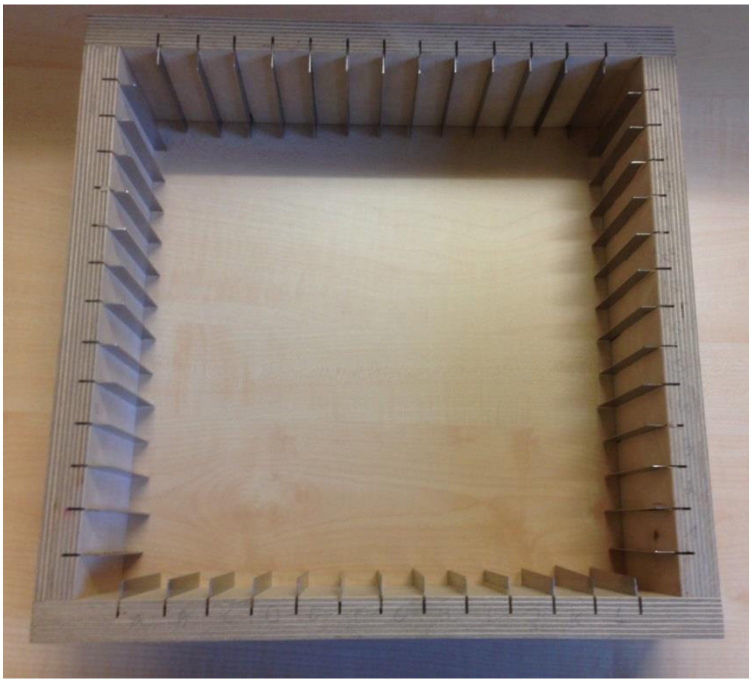


Figure 29. Wooden frame

4.9.3 Mat Preparation

Before forming the veneer mat, the weight of the used steel press plate and the release paper were determined.

Subsequently, the strips were labeled and placed in the box. The labeling was carried out according to a three-axis coordinate system "1-12 / AL" and a value of "1-12" for the respective position of the strip. Figure 36 shows a pre-labeled veneer in the flexural design. Each strip can be assigned a fixed place in the framework set by the indices. The strips were visually checked for errors during layup. Strips with branches or fractures were sorted out.

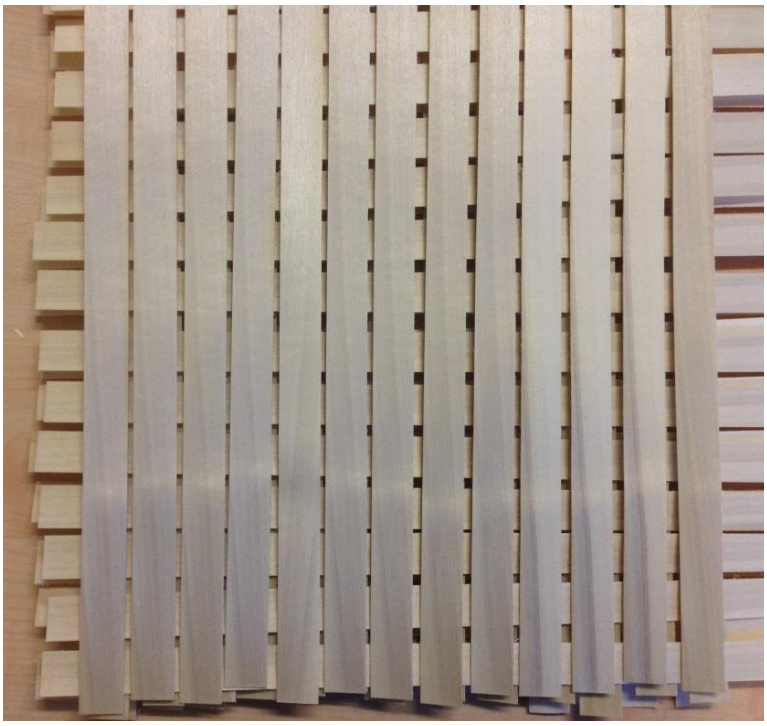


Figure 30. Making the mat (mat A)

After layup of the mat and removing the forming frame, the weight of the mat including the release paper was taken. From the mat weight the density was calculated (before and after pressing)

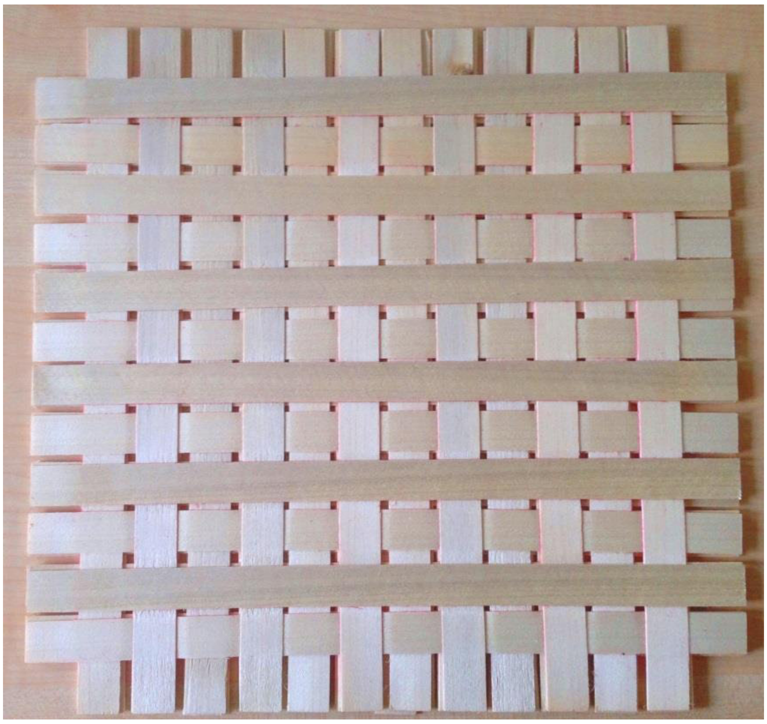


Figure 31. Mat veneer strips before compaction (mat B)

4.9.4 Strips Gluing

Common methods for the application of adhesive on particles and fibers are not suitable for veneer strips. The strips would remain at the bottom of the drum blender and homogeny glue application would not be possible. To avoid this problem, an airbrush technique was applied. UF resin was used as adhesive. Sets of 36 veneer strips were arranged in a square.

Figure 32 shows a fixed position after gluing strips of veneer. For the application of UF resin, SATAminijet 3000B was used. The spray gun was equipped with a 125 cm^3 plastic cup, was connected to compressed air supply and used in accordance with instructions for use with an inlet pressure of 3 bars.

The amount of UF resin was weighted according to the weight of 36 strips of veneer and provided in small measuring cups. The spray gun was recharged for each layer. The sequence can be divided into the following steps and ran from the application of the UF resin over a period of 20 minutes.

1- Counting and weighing of each veneer strip 36

2- Laying and fixing the veneer strips

3- Weigh the UF resin, addition of the indicator and deployment in a measuring cup for each of three layers

4- Spray the glue

5- Decrease the setting frame and weighing the pressing plate, a release paper and the mat

6- Placing a second release paper and the upper press plate

7- Insertion into the press and the start of the press program

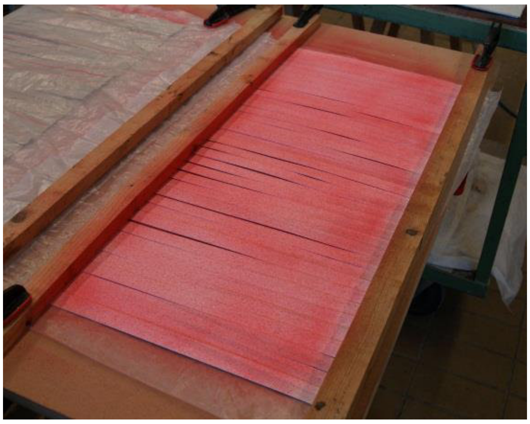
 

Figure 32. Fixed veneer strips by gluing with UF resin (left) and setting frame with UF resin glue-coated veneer strips (right) [Source: Leleicke 2012]

4.9.5 Preparing the Press and Implementation of the Compression

The press was preheated to operating temperature and calibrated according to standard operating procedures. Then the calibration was applied by an automatic control program. The mat, including two press plates with release papers were inserted into the press. The process was monitored on the control computer.

4.9.6 Veneer Mat Compression Parameters

In order to obtain comparable results, two different temperature levels were chosen. Each experimental set was performed at 180°C and 220°C. The lower value indicates the common temperature used in the production of OSB. The upper value is higher than normal temperatures for OSB production and was chosen to detect any effect of temperature and densification behavior.

The target thickness for all experimental was set to 5 mm. This corresponds to 12 layers of 1 mm thick stripes compressed to 41 % of the original thickness. The total time of the pressing operation was 340 seconds. This includes 10 seconds at the beginning and ending of the process for closing and opening the press. Within the first 10 seconds to closing the press to 5 mm, the maximum hydraulic pressure was measured at 25000 kPa on the mat. During the next 320 seconds, the press control kept the target thickness.

After the opening the press, the mat was removed and weighted after a brief visual inspection. This obtained weight could be used to determine the moisture loss. The values entered are examples of the percentage change in thickness from the measurements immediately after pressing and after 24h. In case of bonded veneers with UF resin, 16 points to determine the thickness was defined. Storage for 24h was carried out under standard conditions (20 °C/ 65 %) in a climatic chamber. After 24h, the thickness was measured on the specified measuring points again with the thickness measurement device. From both measurements the springback/ thickness swell was calculated.

5 Results and Discussion

The main idea for selecting beech and poplar for this project was to find a replacement for and reduce the usage of pine as the current main raw material for OSB in Europe to make OSB with the same or even better properties compared to pine based OSB. It was clearly observed that the density of species plays the most important role on all technical properties of produced boards. Given that beech has a higher density compared to pine, using it as raw material for OSB presented the main challenge to this project. The question was if beech with a density between 600-650 kg/m^3 needs higher hot-press pressure and if this is a problem for the industrial scale process. The hypothesis was that given the higher density of beech, this kind of material will compress lower during hot pressing to reach the nominal thickness and the compaction rate will be lower than pine with the same board design. Therefore, it may impact on the physical and mechanical properties of final boards and also need modification such as by higher press pressure.

In this research, the press program was set on nominal thickness of boards. It means after closing the press plates to reach the nominal thickness (16 mm) the press pressure no longer had any detectable influence on mats. The only difference between different mats (design and combinations) that could be recorded was the time of press closing to reach the target thickness of 16 mm. Regarding the experience in the lab during panel production, only panels made of pure beech (100 %) with normal sized strands showed a longer press closing time to reach the thickness. For almost all panels the mats were compress to the till target thickness within15 and 25s, even for panels made of fine beech strands in the core layer (normal sized strands in face and fine contents in core layer). For panels made of 100 % beech this time was around 50-60s. But still the overall press time was the same as for all boards.

Based on the explanation mentioned above, no special modifications were made to the beech based OSB. The results of this project show the higher density of beech would not be a limitation for using this species as a replacement for pine or in combination with pine to make OSB. The results indicate using beech in the face layer and poplar in core, not only approves the technical properties of OSB compared to EN standard, but also provides a new raw material without any particular concerns for the producer in terms of higher density.

According to the main goals of the project, this chapter is structured into five sub chapters:

A) Application of normal sized strands from beech and poplar in face and core layers
B) Using fine core materials in core layer
C) Mixture of beech and poplar strand and mixed with pine
D) Veneer densification
E) VOC

5.1 The Applications of Normal Strands in Face and Core Layers

OSB application has grown remarkably in recent years, making OSB an important wood-based panel product. Globally, OSB plays a significant role in the building sector, especially in North America and Europe. The initial attempts to produce OSB were made back in the 1960s. Once on the market, this new product was able to compete with plywood and particleboard. Today, plywood in particular is under pressure due to a shortage of high quality logs with medium/ large diameters, to growing environmental concerns and to the cost of plywood manufacturing. OSB has firmly established its market place in North America and since the year 2000 has penetrated the European market for structural applications. OSB is widely used for various applications such as wall and roof sheathing, flooring, packaging and, I-joints. It is also used in other structural applications such as furniture, reels pallets, boxes, trailer liners and recreational vehicle flooring (Hiziroglu 2006, Irle et al. 2013).

A sustainable OSB market is very closely linked to the supply of raw materials. In contrast with plywood, the supply of raw materials for OSB market is quite vast, given, for example, the abundance of low quality logs and species with lower diameters. Nevertheless, it is important to select suitable species to produce OSB so that good practical properties as well as feasible large volumes can be achieved.

The use of hardwoods as raw material for OSB is quite new in Europe, and currently no OSB panels are made from 100% hardwood species. Previous research based on the possibility of using certain hardwoods together with pine exists, but the study was not extensive (Beck et al. 2009). Han et al. 2005 examined the influence of fines content and panel density on properties of small-diameter mixed hardwoods such as oak, cottonwood and hackberry.

5.1.1 Overview of Results

The average and standard deviation of values of modulus of rupture, modulus of elasticity and internal bond are given in Table 8 and the thickness swelling of produced panels are also available in the table. In general, with increasing density, all mechanical properties and also the internal bond increased except the MOE and IB for panels J and G, respectively. These results support finding by Chen et al. (2010), Sumardi et al. (2007), Han et al. (2006), Nishimura et al. (2001), Vital et al. (1974). The results also indicated TS values increased with increasing density but the inverse effect was recorded for pure beech panels and panels having the core made by beech strands. It is well know that the TS values have a direct correlation with density and will increase with increasing panel density (Wu and Piao (1999), Gatchell et al. (1966), Roffael et al. (1972), Yale (1956), although some researchers showed contradictory result. Liu and McNatt (1991) investigated thickness swelling and density variation in aspen flakeboards and conditioned these panels at 80 % RH for 71 days and found no clear relationship between density and TS. However, increases in mechanical strength with increases in density can be sufficient to offset increased swelling tendency (Lehmann 1960), and high density can increase the efficiency of resin usage, therefore reducing thickness swelling (Clad 1967).

Table 9. Physical and mechanical properties of OSB boards

Panel	Density(g/cm^3)	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	TS(%)
A1	0.63(0.02)	35.8(4.3)	6317(200)	0.4(0.13)	16(3)
B1	0.73(0.01)	52.5(5.4)	6888(331)	0.7 (0.08)	12(2)
C1	0.66(0.03)	23.7(2.8)	4980(212)	0.3(0.1)	19(3)
P1	0.71(0.04)	42.4(6.5)	5443(696)	0.6 (0.13)	23(3)
K1	0.62(0.01)	54(6.3)	6039(458)	0.8 (0.14)	10(1)
F1	0.73(0.03)	59(1.7)	7066(633)	0.99(0.19)	11(4)
D1	0.66(0.05)	39.5(5.1)	4956(211)	0.5 (0.18)	12(3)
E1	0.71(0.03)	49.3(6.3)	5843(100)	0.5 (0.08)	20(3)
L1	0.64(0.05)	34.7(8.3)	4693(219)	0.5(0.12)	15(2)
G1	0.7 (0.04)	41.2(3.6)	5634(684)	0.2 (0.03)	25(4)
M1	0.64(0.03)	42(3.2)	5967(137)	0.5 (0.12)	16(3)
J1	0.71(0.06)	47.1(4.8)	5490(563)	0.5 (0.06)	14(4)
H1	0.63(0.02)	47.8(4.17)	5310(254)	0.6 (0.14)	13(3)
I1	0.74(0.04)	50(4.4)	6050(460)	0.7(0.19)	9(4)
O1	0.65(0.03)	39(6.07)	4415(758)	0.7(0.25)	11(3)
N1	0.74(0.02)	42.5(4.2)	5330(447)	0.8 (0.2)	6(2)

Standard deviation in parentheses, MOR: modulus of rupture

MOE: modulus of elasticity, IB: internal bond, TS: thickness swelling after 24h

Table 9 also illustrated that all properties meet the current standard of minimum requirement for OSB2 with exceptions of IB and TS for panel G and also TS for panel P.

5.1.2 Vertical Density Profile

In general, high density surface and low -density core layers are typically distinguished VDP in OSB. To avoid overcrowded curves, only the VDP from pure beech and poplar at 50-50 % ratio for both densities are presented. Figure 33 reveals that the average VDP of poplar in both densities are lower than beech and also clearly shows that the average density of panels with 720 kg/m^3 density are higher than 650 kg/m^3. The formation of such a profile is combined from the results of gradients of temperature, moisture content, and pressure in strand furnish during pressing (Strickler 1959; Suchsland 1962; Wolcott et. al 1990; Winistorfer and Wang 1999 & Chen et al. 2010). The influence of VDP on properties of OSB was the topic of several pervious researches (Xu 2007; Gu et al. 2005; Jin et al. 2009) and this research confirmed these results because of higher amount of beech panel properties.

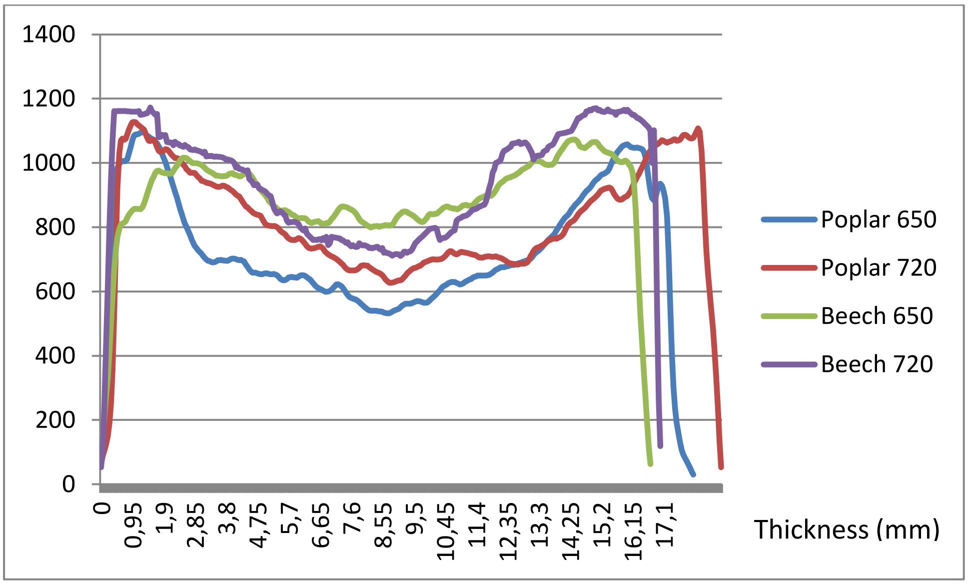


Figure 33. Vertical density distribution of OSB made from pure beech and poplar strands

5.1.3 Bending Strength

In general, by increasing the amount of core layer or, on the other hand, by decreasing the surface thickness from 60 to 25% the bending strength decreased, although the correlation between decreasing MOR and MOE in panels made of beech were not as strong as panels made by poplar in core layer.

In OSB with core made of beech strands, with decreasing the surface thickness from 60 to 50 %, the MOR and MOE slightly increased for both densities. When the surface thickness was lowered to 25% the bending strength continued to decrease (Fig. 35).

While the lowest MOR value (23.77 N/mm^2) was measured for panels produced only from poplar strands (panel C) with 650 kg/m^3 density was calculated, the highest value (59 N/mm^2) was obtained at 720 kg/m^3 density and 60% beech strands in surface layer (panel K) which is almost three times higher than standard requirements (Fig. 36).

This study observed the same trend in highest MOE for panels manufactured from 60 % beech strands in faces. The highest and lowest values of MOE were 7066 and 4415 N/mm^2 for panels F and N, respectively (Fig. 38 and 39). These results indicated that the surface layer plays an important role in bending strength and the thickness of face and also alignment could improve the MOR and MOE.

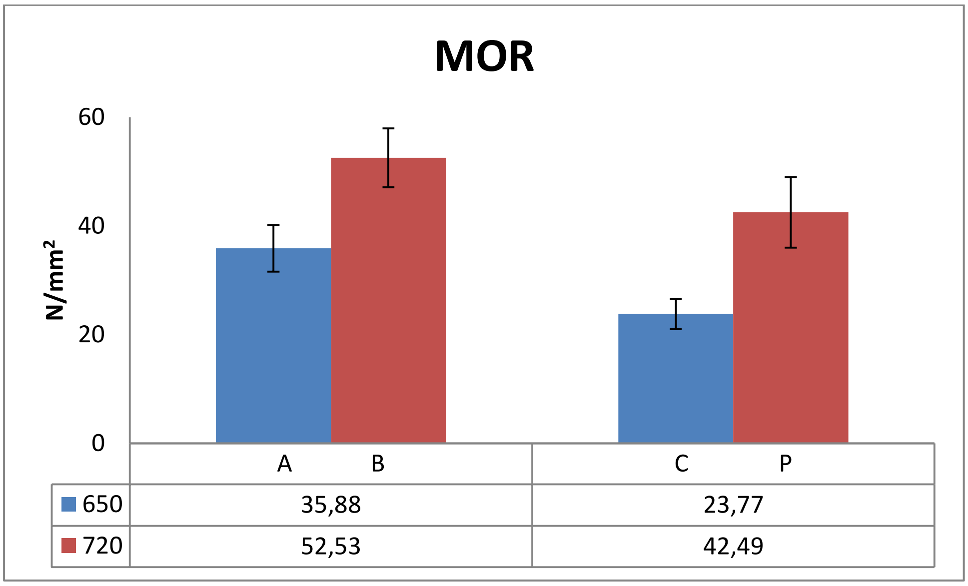


Figure 34. Average MOR of pure beech and poplar strands based core 16 mm OSB

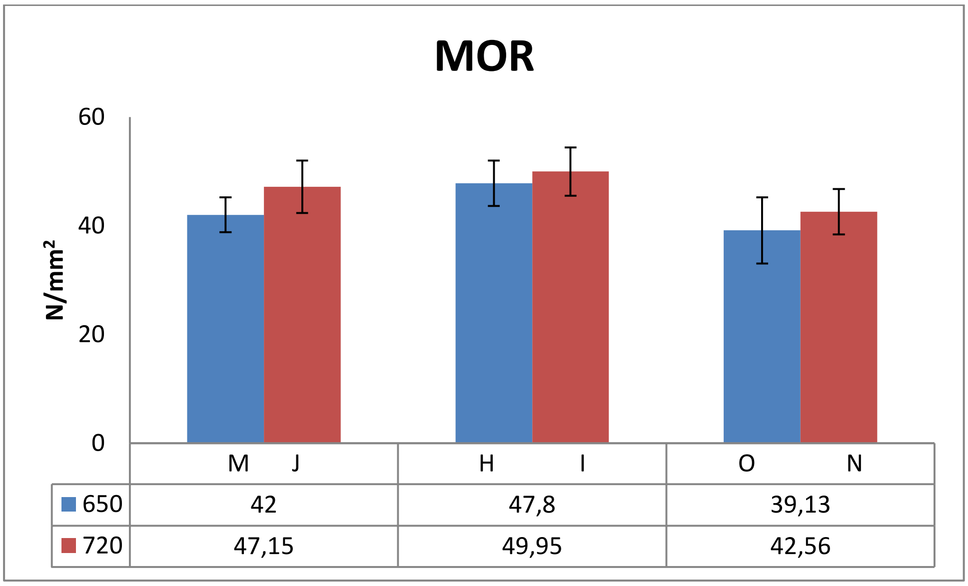


Figure 35. Average MOR of beech strands based core 16 mm OSB

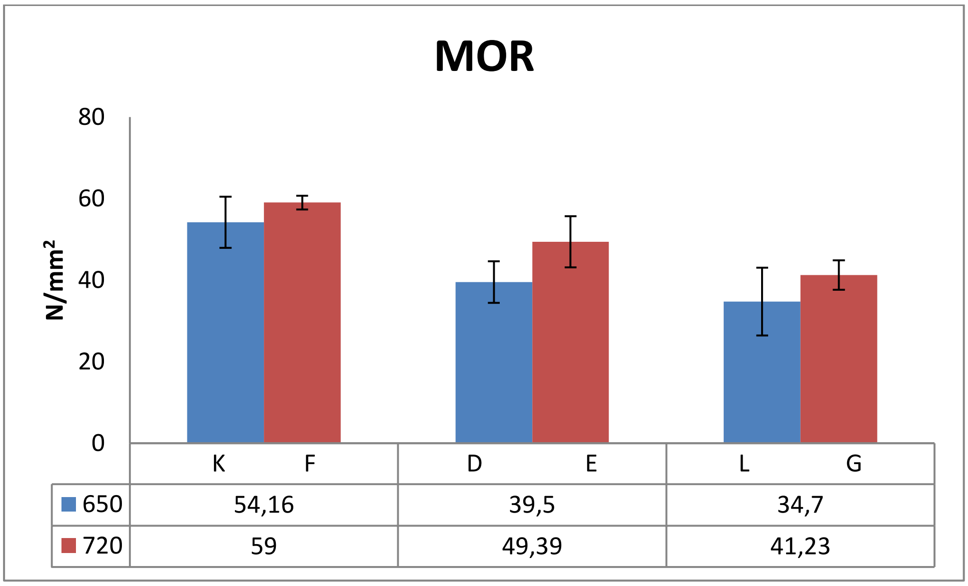


Figure 36. Average MOR of poplar strands based core 16 mm OSB

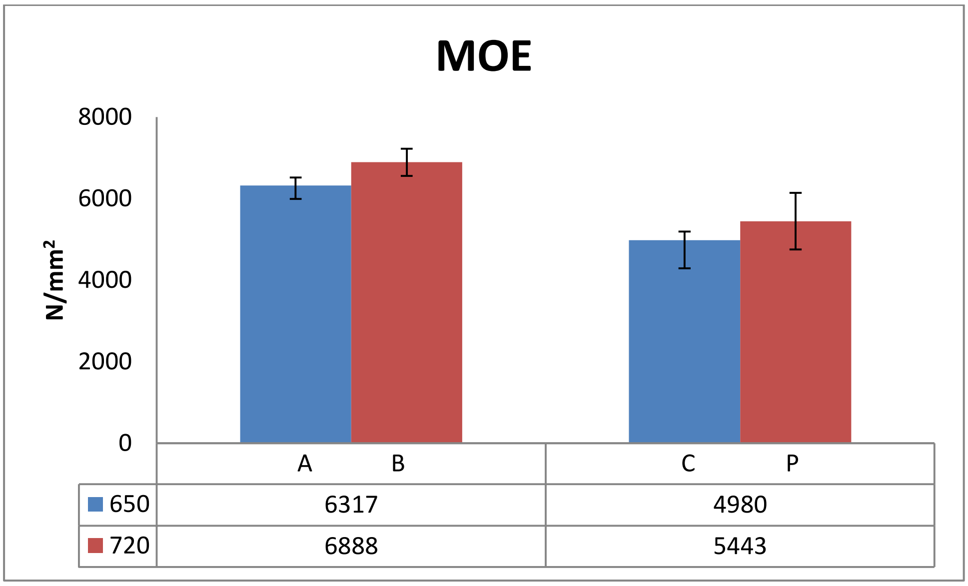


Figure 37. Average MOE of pure beech and poplar strands based core 16 mm OSB

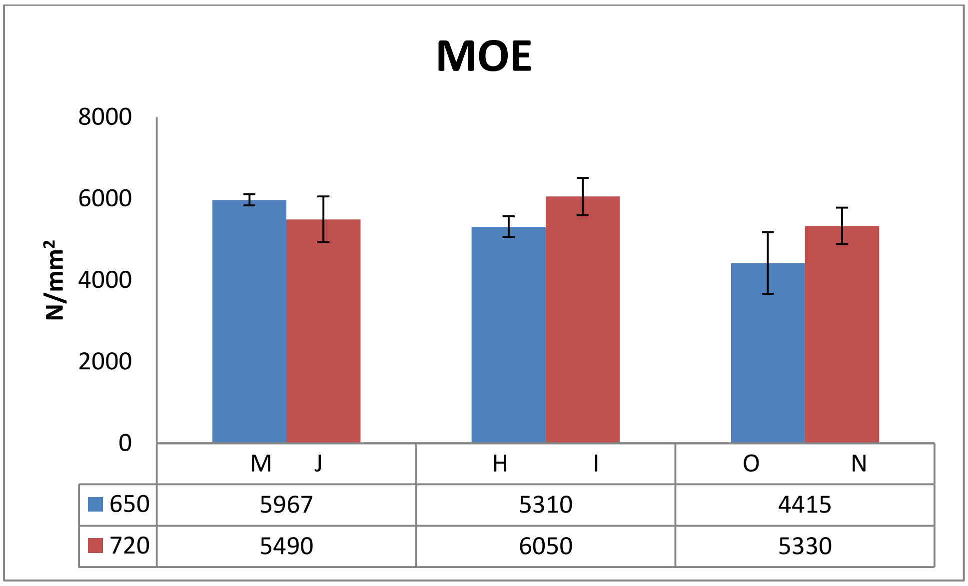


Figure 38. Average MOE of beech strands core 16 mm OSB

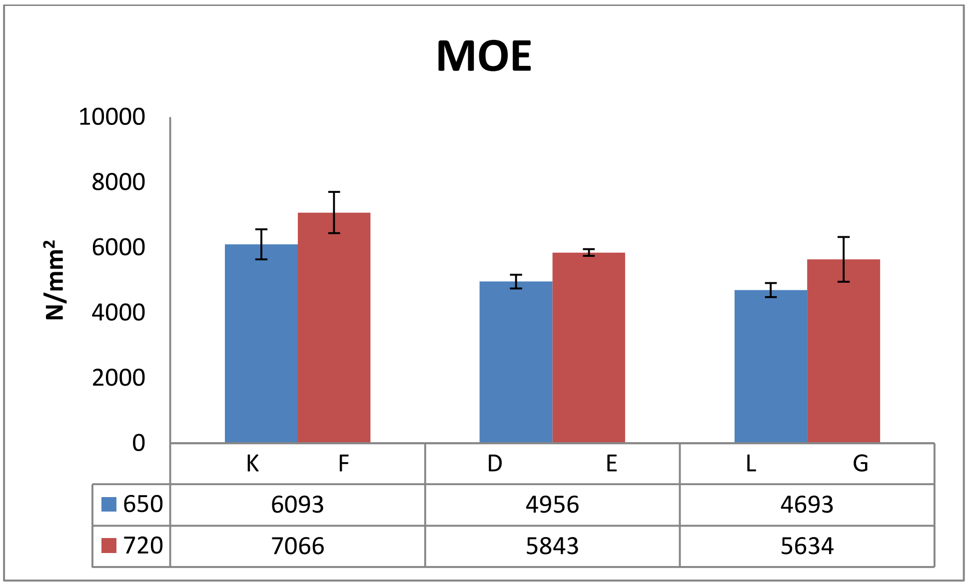


Figure 39. Average MOE of poplar strands based core 16 mm OSB

5.1.4 Internal Bond

The results showed that the internal bond values of the test samples varied between 0.3 and 0.99 N/mm^2. Mean IB strength of all boards was higher than the minimum requirements for OSB2, which is 0.3 N/mm^2, except panel G. In addition, IB increases with the density which corresponded to previous findings in research studies such as (Dai et al. 2008; Jin et al. 2009).

When the amount of poplar strands was increased in the core layer from 40 to 75 %, the internal bond decreased from 0.99 to 0.27 N/mm^2. By increasing the amount of beech strands in the core layer the adverse trends were recorded. 0.81 N/mm^2 was the maximum IB, reached by panels with 75% beech strands in core at 720 kg/m^3 (panel N). Due to higher density of beech compared to poplar, it appears that the moisture transfer from surface layers into the core has a positive effect in presence of heat and resulted plasticization behavior in core layer and this increase the flexibility of beech strands in contact with resin during the mat consolidation. In case of increasing the poplar strands amount in core layer, because of lower density and probably the weakness of wood-resin bond, the internal gas pressure during hot pressing led to break these bondages. This decreasing rate for panel with 720 kg/m^3 density was clearly observed because of higher amount of strands and increased internal gas pressure during hot pressing.

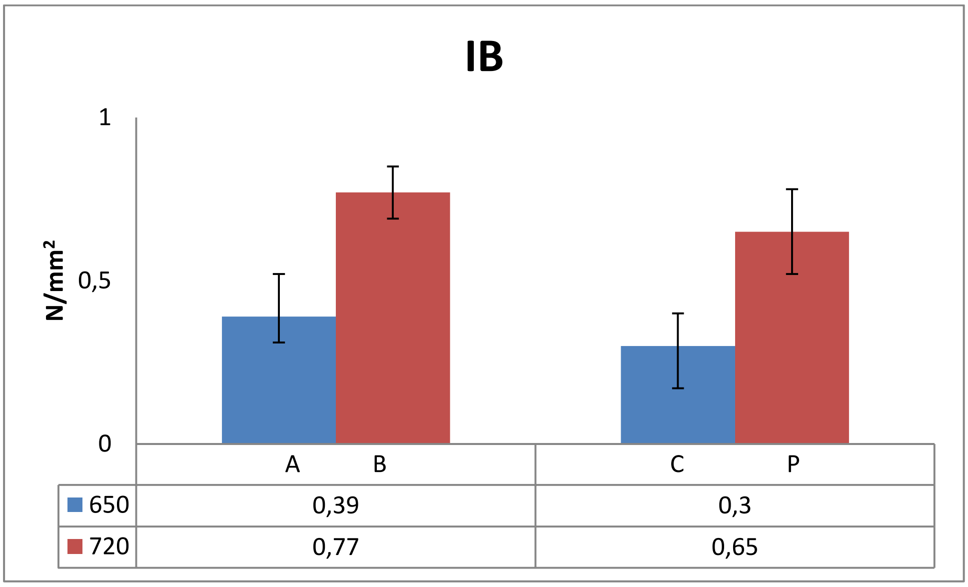


Figure 40. Average IB of pure beech and poplar strands based core 16 mm OSB

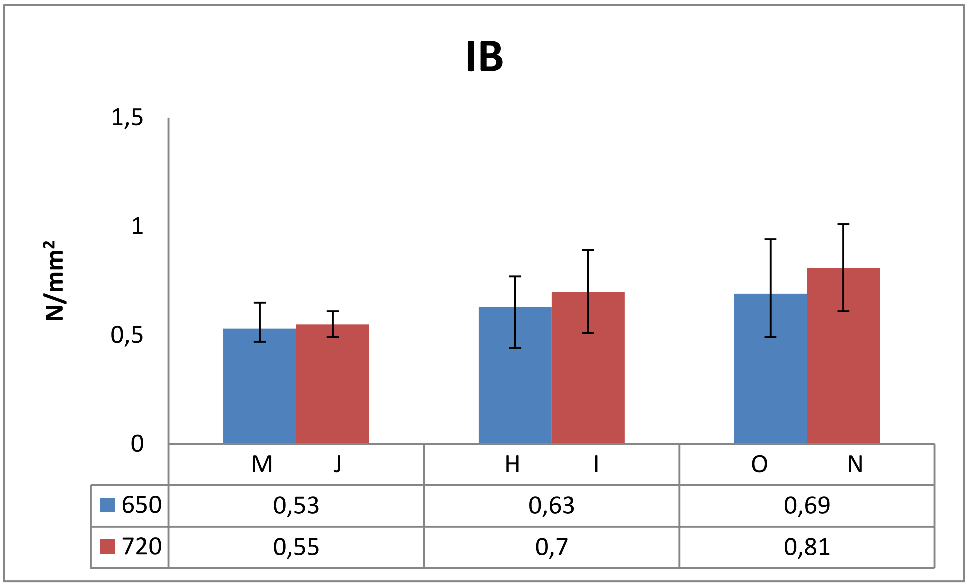


Figure 41. Average IB of beech strands based core 16 mm OSB

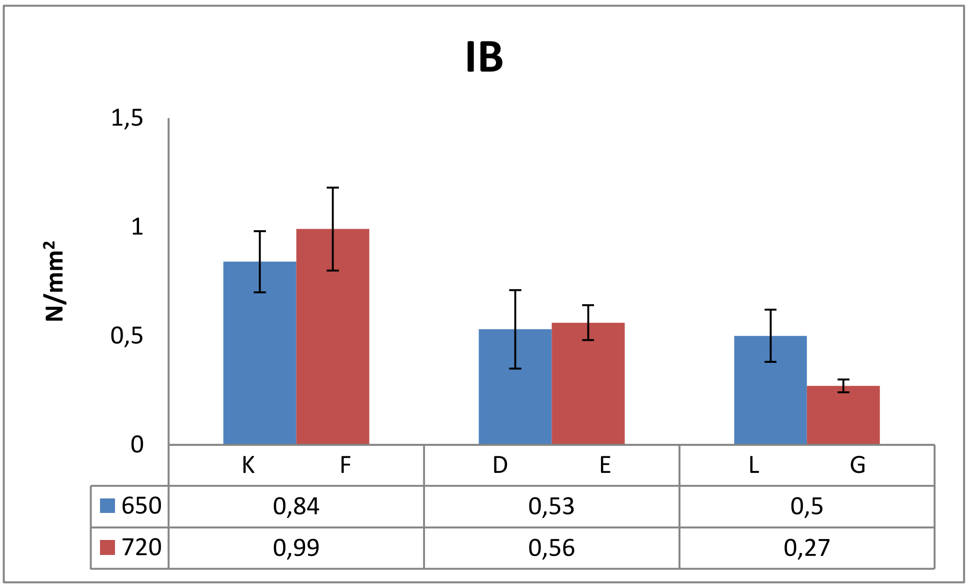


Figure 42. Average IB of poplar strands based core 16 mm OSB

5.1.5 Thickness Swelling after 24h

It was discovered that the thickness swelling rate ranged from 6 to 25 % after the sample had been kept in water for 24h. The lowest and highest values of TS were achieved by the panels made of 75 % poplar and beech strands core layer, respectively (Fig. 44 and 45). Although no wax was used during panel manufacture overall dimensional stability of the panels are within acceptable range compared to European standards with the exception of 100% poplar strands and panel G. The results also showed TS values in panels made by beech strands core layer decreased with increasing density. Chen et al. (2010) investigated relationship between major properties of OSB and panel density by carrying out a systematic and extensive pilot plant experiment. In their research, TS and WA linearly decreased with increasing panel density. They observed that higher density products absorb water slower, reducing the rate of TS.

In addition, increased bonding in the core layer due to the positive influence of moisture during hot pressing led to an increased resistance against water penetration and decreased the thickness swelling. The thickness swelling of beech and poplar strands with and without resin after 24 hours was also examined. In this test it was clear that poplar strands absorbed more water compared to beech strands because of lower density and higher permeability which could be the other reason for TS reduction in panels made by using higher amount of beech strands.

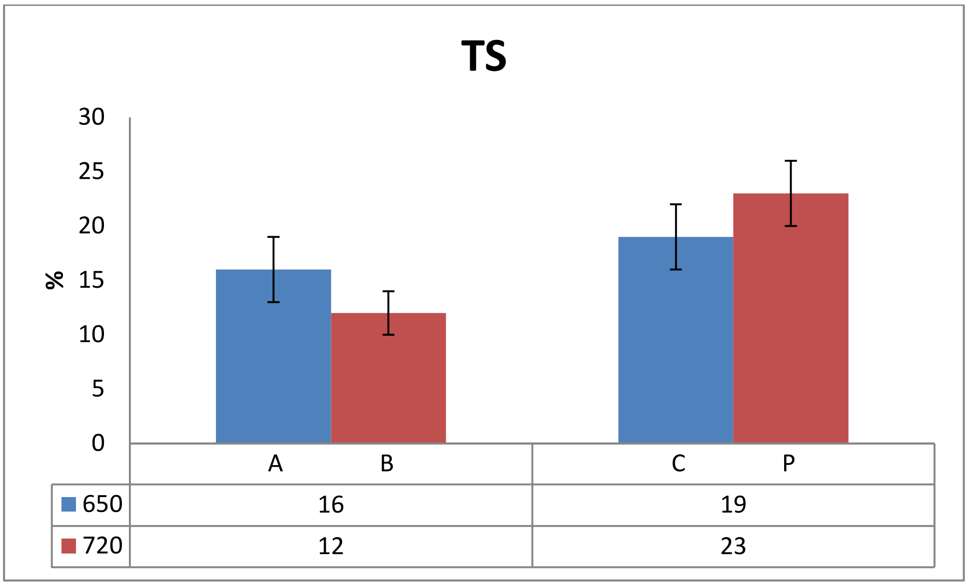


Figure 43. Average TS pure beech and poplar strands based core 16 mm OSB

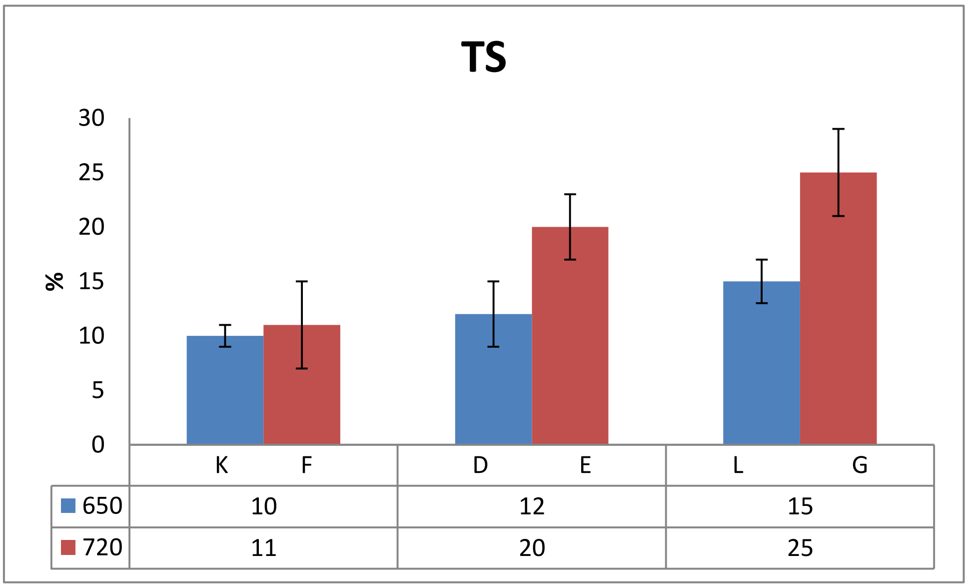
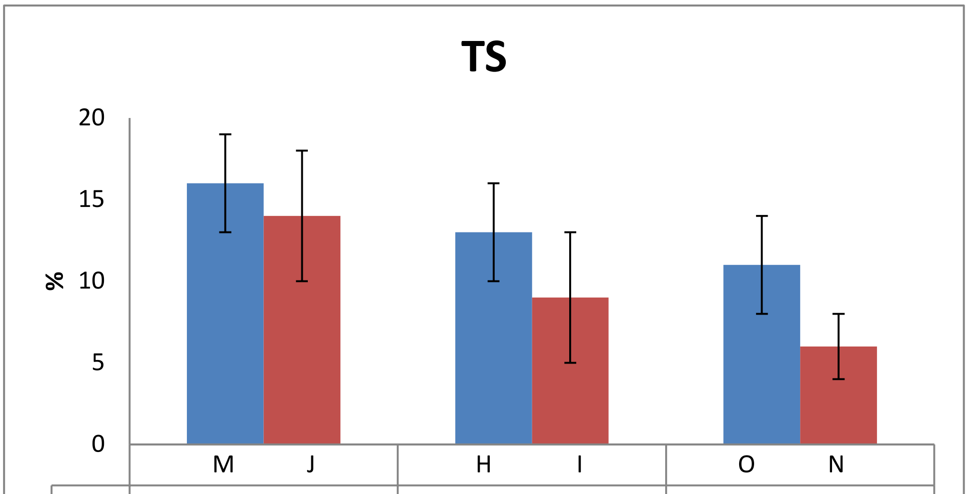


Figure 44. Average TS of beech strands based core 16 mm OSB



650	16	13	11
720	14	9	6

Figure 45. Average TS of poplar strand based core 16 mm OSB

5.2 Using Fine Materials in Core Layer

In Europe, developments between 2003 and 2010 show a 50 % increase in OSB capacity with a projected growth trend continuing until 2019 (Anonymous 2012). Manufacturing expense is another aspect of OSB production. Producers today are searching for cheaper and even lower quality raw materials to convert into value added products. After resin, wood represents the second greatest portion (31 %) of wood based panel production costs (Anonymous 2010). This study used small diameter European beech and poplar as raw materials to produce OSB. Since beech and poplar currently are used mainly as fuel for heat and power generation, they might offer a cheaper alternative to pine, which is the conventional raw material for most OSB mills, and also in high demand by other sectors. Another aspect of this study is the possibility of a reduction in production costs by using fine strands in the OSB core layers. Only a very few basic studies have been published on the effect of varying amounts of fines material, their location in the OSB structure, and final board properties (Han et al. 2007, Mirski and Dziurka 2011). Theoretically, OSB face layers should consist mainly of thin and long strands of 8-15 cm in length and 0.3 to 0.7 mm thickness.

The generation of fine strands is inevitable during the flaking process. Depending on the log size and condition, 20-40 % of the total strand mass produced is fine material which is defined as strands that pass through a 3.18 mm square opening (Fakhri et al. 2006). The easiest way to use these small strands is for energy or particleboard production, but adding this material to the core layers of OSB could reduce production costs. Previous research showed that using flakes with a small amount of chips in the core layer (up to 30%) does not significantly reduce the mechanical properties of the resulting OSB panels (Brinkmann 1979, Ehrentreich 1980, Barnes 2002, Jastrzab 2008). However, the fine strands change the internal mat structure and influence panel properties and the pressing process (Han et al. 2007). Using beech and poplar in OSB manufacturing is fairly new and will require further research into the different aspects of these new products (Akrami et al. 2014a).

5.2.1 Overview of the Results

The average values of modulus of rupture, modulus of elasticity, internal bond and thickness swelling of all panels are presented in Table 10 and Figures 46 through 50. The mean density was between 0.6 and 0.63 g/cm^3. Panels A with 10 % fine beech in core layer showed the lowest density and, 0.637 g/cm^3 was the highest density for panels F and G made by 30% fine poplar strands in the core layer. Except thickness swelling of panels made by 10 and 30% fine beech strands in the core layer, other panels showed higher values of mechanical properties, IB and TS compare to EN300 standards. According to Fig. 53 and 54, although the panels could reach the minimum requirement for OSB type 2 but between different treatments, panels made by pure poplar with 30 % fines in core layer showed the highest MOR and MOE among all. The correlation between IB and TS indicated that panels with 50 % poplar in core layer and normal beech strands in faces showed the highest IB and the lowest TS.

Table 10. Physical and mechanical properties of fine core OSB boards

Treatments	Panel Type	Core Fine Proportion %	Density (g/cm^3)	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	TS 24h (%)
A2	B	10% Fine	0.60	30,3 (7.4)	6797 (533)	0.26 (0.03)	18 (6)
B2	B+P+B		0.61	46.9 (5.6)	6662 (794)	0.65 (0.09)	17 (1)
C2	P+B+P		0.62	30.75 (3.3)	6544 (499)	0.21 (0.05)	28 (6)
D2	P		0.63	63.35 (7.3)	8301 (650)	0.9 (0.05)	14 (2)
E2	B	30% Fine	0.63	43 (5.5)	6837 (550)	0.6 (0.09)	14 (3)
F2	B+P+B		0.63	56.47 (8.7)	7523 (631)	0.99 (0.14)	12 (2)
G2	P+B+P		0.62	39.25 (5.3)	8464 (733)	0.46 (0.13)	21 (8)
H2	P		0.63	71.27 (6.5)	9882 (164)	0.93 (0.13)	14 (3)
I2	B	50% Fine	0.63	39.37 (12.2)	7523 (770)	0,52 (0.09)	13 (2)
J2	B+P+B		0.61	67.94 (5.5)	7338 (1140)	1.2 (0.18)	10 (1)
K2	P+B+P		0.63	43.49 (3.3)	8751 (709)	0.43 (0.14)	20 (6)
L2	P		0.63	65.44 (5.8)	8843 (598)	0.72 (0.07)	11 (2)

5.2.2 Bending Strength

The results of MOR and MOE for different core layer composition are illustrated in Figure 46 and 47. In general with increasing the fine materials from 10 to 50 %, the MOR and MOE increased although there is no clear difference between panels made with 30 and 50 % fines. It is well known that bending strength and modulus of elasticity are highly related to the face layer of panels. Therefore, the normal strands determined that these mechanical properties and fine materials did not have essential impact on board properties. Similar results were reported in a study by Mirski and Dziruka (2011). They investigated the utilization of chips from comminuted wood waste as a substitute for flakes in the oriented strand board core. Their results showed that the applied modification did not have a significant effect on bending strength or MOE determined in the longer axis of the OSB. In addition, Han et al. (2007) studied the influence of fine contents and panel density on properties of mixed hardwood oriented strand boards and indicated that there was no consistent variation on the bending properties as fines content increased in the core layer. Table 10 indicated all panels reached the minimum requirement for OSB type 2 (EN300) for mechanical properties that are 20 and 3500 N/mm^2 for MOR and MOE in longer axis, respectively. Panel H reached the maximum MOR and MOE with 71.27 and 9882 N/mm^2 respectively. The other remarkable point between panels was the MOR values of panels made of beech fine materials in core layer. These groups of panels showed the minimum MOR values, however, was higher than EN standard. During bending test, the shear failure was occurred in the core layer thorough the length. Therefore, it might be the reason of lower MOR.

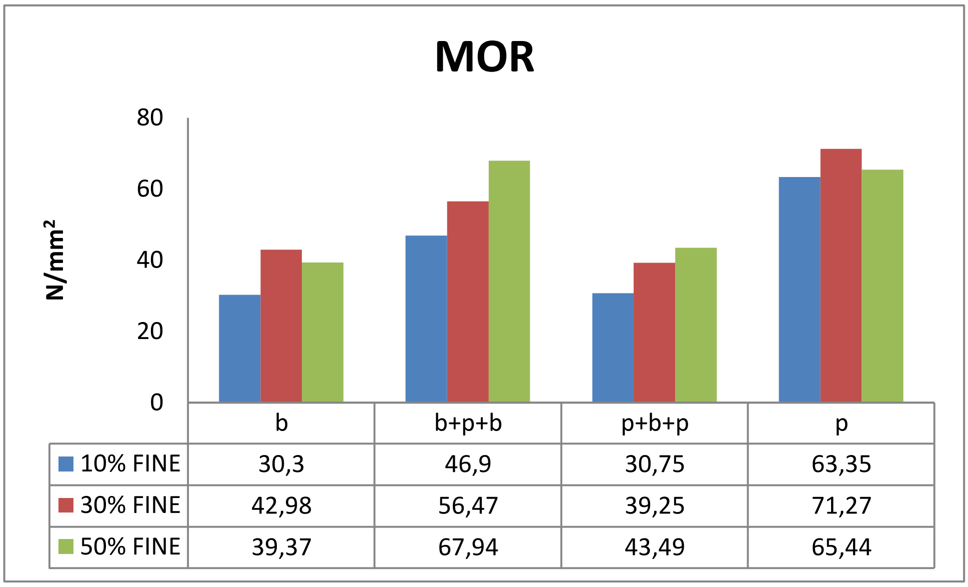
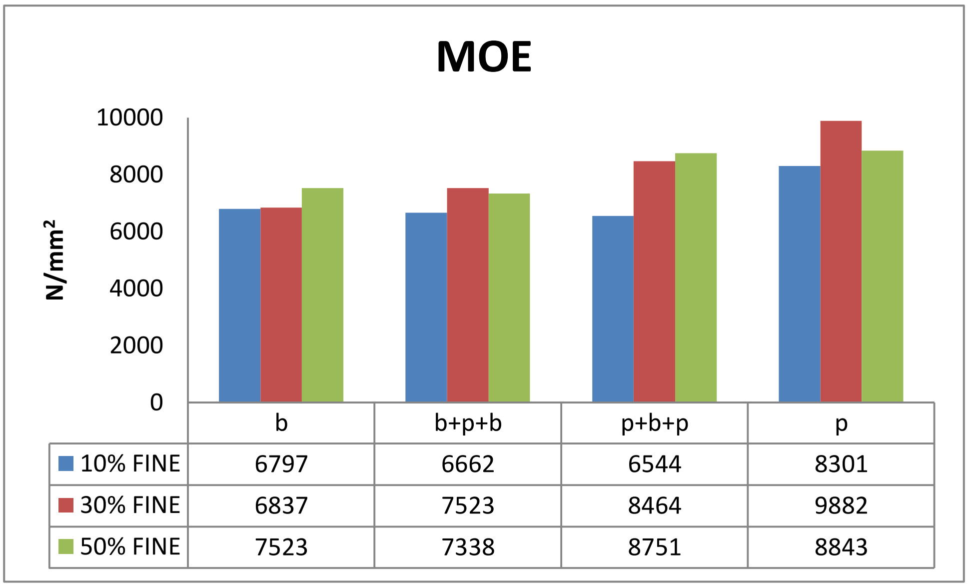


Figure 46. Average MOR of fines core layers of 16 mm OSB



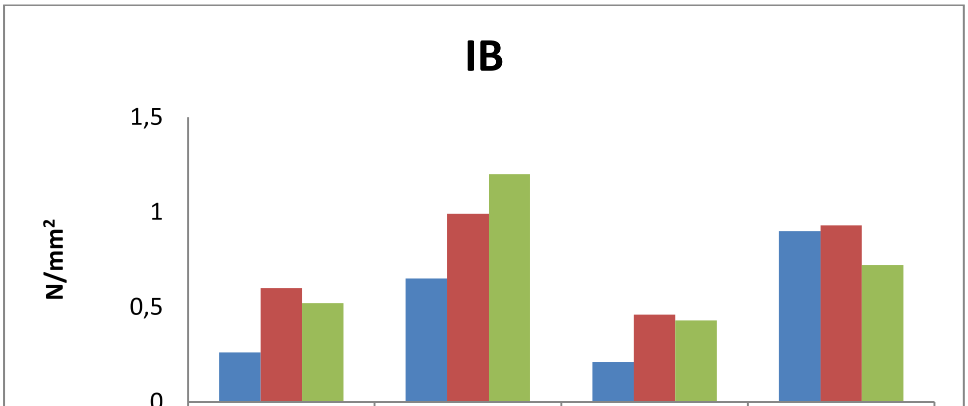
	b	b+p+b	p+b+p	p
10% FINE	6797	6662	6544	8301
30% FINE	6837	7523	8464	9882
50% FINE	7523	7338	8751	8843

Figure 47. Average MOE of fines core layers of 16 mm OSB

5.2.3 Internal Bond

With an increased amount of fine strands in the core of OSB to 30 %, the IB in all panels was improved. Except panel H, the boards made with 30 % fines in the core layer showed at least 50% increase in IB compared to 10 % fines. It seems the fines material functions as filler between the normal strands to close the voids and in the presence of pMDI resin, could improve the core layer improve properties. These results are in line with finding from the previous research on using fines material for OSB manufacturing (Han et al. 2007).

With increasing fines content from 30 to 50 %, no major influence was observed. Panels made with 10 % fine beech in core and normal poplar strand in faces, showed the minimum IB value. During the internal bond test, normally the IB failure occurred in core layer, but in these samples the failure was observed in the interface between beech and poplar strands.



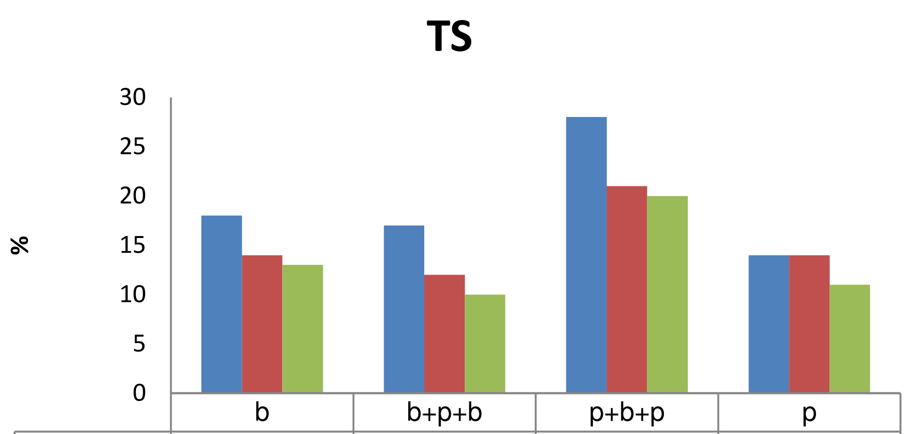
	b	b+p+b	p+b+p	p
10% FINE	0,26	0,65	0,21	0,9
30% FINE	0,6	0,99	0,46	0,93
50% FINE	0,52	1,2	0,43	0,72

Figure 48. Average internal bond of fines core layer of 16 mm OSB

5.2.4 Thickness Swelling & Water Absorption after 24h

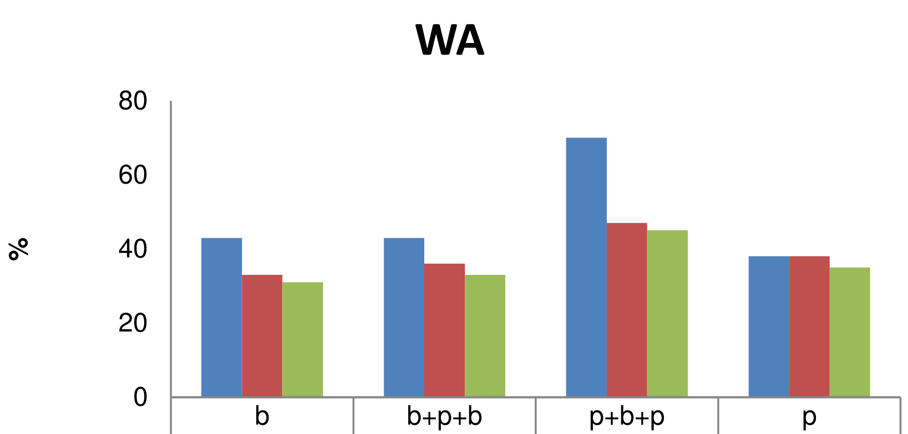
The results of thickness swelling and water absorption after 24h are showed in Fig. 49 and 50. In general, with increasing fines content, TS values decrease. Only panels made with beech in the core showed very high thickness swelling, even above the EN300 standard. Although, these panels can reach the maximum acceptable EN300 requirement at 50 % fines in the core. Panels with 100 % beech or poplar showed the lowest thickness swelling after 24h, with 13 and 11 %, respectively. The panels showed no significant variation in TS between 30 and 50 % fine in core layer. Between these four panel groups, panels made with fines beech in the core and pure poplar strands showed the maximum thickness swelling. Although with increasing fines from 10 to 50 %, the thickness swelling was modified from 28 to 20 %. Compared to panels made by poplar fines in the core, it was found that poplar could have a proper connection with pMDI resin and produce a high quality bondage that leads to increasing resistance to water absorption and IB.

Figure 50 shows that WA had the same trend as TS. With increasing fines material in core layer from 10 to 50 %, the water absorption decreased. Han et al. (2007) investigated the influence of fines content and panel density on properties of mixed hardwood oriented strand board. In this research, the results indicated that the difference between linear expansion (LE) values was reduced with increase of fines content in the boards.



	b	b+p+b	p+b+p	p
10% FINE	18	17	28	14
30% FINE	14	12	21	14
50% FINE	13	10	20	11

Figure 49. Average thickness swelling of fines core layers of 16 mm OSB



	b	b+p+b	p+b+p	p
10% FINE	43	43	70	38
30% FINE	33	36	47	38
50% FINE	31	33	45	35

Figure 50. Average water absorption of fines core layers of 16 mm OSB

5.3 Mixture of Beech and Poplar Strand and Mixed with Pine

It is clear that in the near future supplying suitable raw material will be the main challenge for wood-based panels. In the case of OSB mills and markets, and in light of recent polices aimed at converting European softwood forests into hardwood forests, using alternative wood species in place of conventional raw materials could present a valuable new strategy for producers.

The first part of this study examined European beech and poplar as possible raw materials for OSB in an effort to reduce the pressure on softwood forests and create new opportunities for producers (Akrami et al. 2014a). The research showed that small-diameter beech (20-30 cm) and poplar (24-32 cm) trees are potentially valuable competitors to softwoods, and especially pine, currently the main resource for OSB mills in Europe.

The second part, focused on the physical and mechanical properties of fines in the core layer with different percentages and designs (Akrami et al. 2014b). The results showed that by using fine strands in core layers, not only could the minimum values for OSB type 2 be reached, but also the use of fines could be key to reducing production costs.

This part of the study evaluated the possibility of using beech and poplar strands in a mixture as well as in a mixture including pine. The properties of boards produced in the lab were compared to the EN300 standards and also to pine panels that were made in the lab with the same conditions. Although pervious research used a mixture of hardwoods with pine in small amount (less than 10 %) nevertheless, hardwoods were not the major part of raw materials for OSB and only a few wood species have been utilized in large quantities for commercial OSB manufacture (Wang and Winistorfer 2000).

5.3.1 Overview of Results

As Table 11 shows, mechanical properties and internal bond increase with increasing density from 650 to 720 kg/m^3. Panels made from a mixture of beech and poplar (panels A and B) reached maximum MOR at two density levels, compared to other panels. Panel D (mixture of beech and pine) showed the maximum MOE with 8174 N/mm^2 at 720 kg/m^3 although the MOE value at

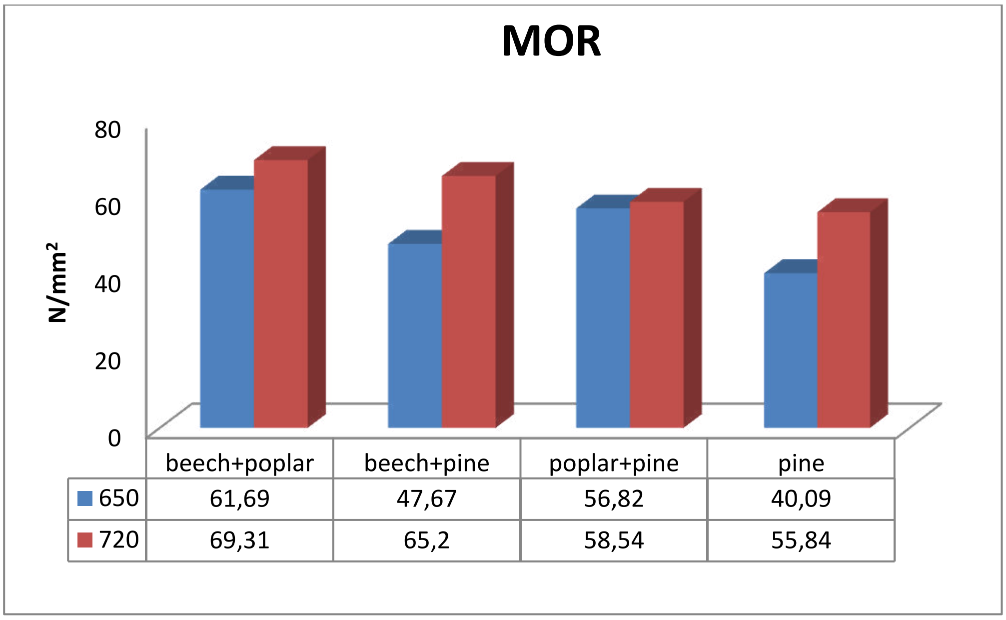
650 kg/m^3 is almost close to the panels made with a mixture of beech and poplar. The other noticeable point was the lower mechanical properties and also internal bond of pure pine panels among the different designs (except MOE at a board density of 720 kg/m^3). For instance, MOR of pine panels showed 53 % lower value compare to mixed beech and poplar panels at 650 g/cm^3. Furthermore, in the case of physical properties, the mixture of beech and poplar strands showed the minimum TS 24h at both densities.

Table 11. Physical and mechanical properties of mixed strands OSB boards

Panel	Density (g/cm^3)	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	TS24h (%)
A3	0.66(0.3)	61.7(6)	6839(520)	0.87(0.17)	13(3)
B3	0.73(0.4)	69.3(8.8)	7031(685)	1(0.16)	6.6(1.3)
C3	0.64(0.1)	47.6(9.8)	6951(856)	0.91(0.13)	23(2)
D3	0.73(0.4)	65.2(5.4)	8174(416)	1.31(0.16)	24(2)
E3	0.62(0.4)	56.8(3.1)	6769(294)	0.61(0.19)	16(3)
F3	0.7(0.2)	58.5(7.2)	7004(223)	1.1(0.11)	18(1)
G3	0.62(0.3)	40.1(4.8)	6043(756)	0.79(0.09)	22(5)
H3	0.71(0.3)	55.8(9)	7306(614)	0.88(0.07)	23(2)

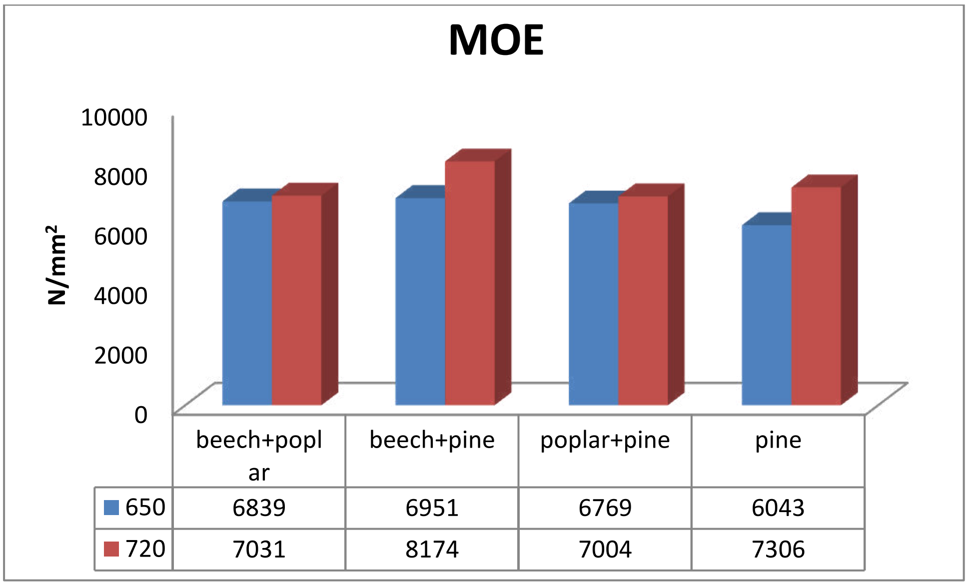
5.3.2 Bending Strength

According to Figures 51 and 52, the MOR and MOE values for the major board axis show all panels reach the minimum requirements for OSB type 2 based on EN300 standards. The results showed that mixing low and high density species (beech and poplar) could create panels with improved properties. It is well known that the strength properties highly depend on density. Comparing panels made with a mixture of pine and beech or poplar strands, OSB panels made with beech and pine showed higher MOR and MOE. This value might be related to higher density of beech strands compared to poplar. Pine based panels reached the minimum values between these panels except MOE at 720 kg/m^3 although it is only 4 % higher than panels B and F that show no significant difference.



	beech+poplar	beech+pine	poplar+pine	pine
650	61,69	47,67	56,82	40,09
720	69,31	65,2	58,54	55,84

Figure 51. The effect of density and different wood species mixture on MOR (n=6)



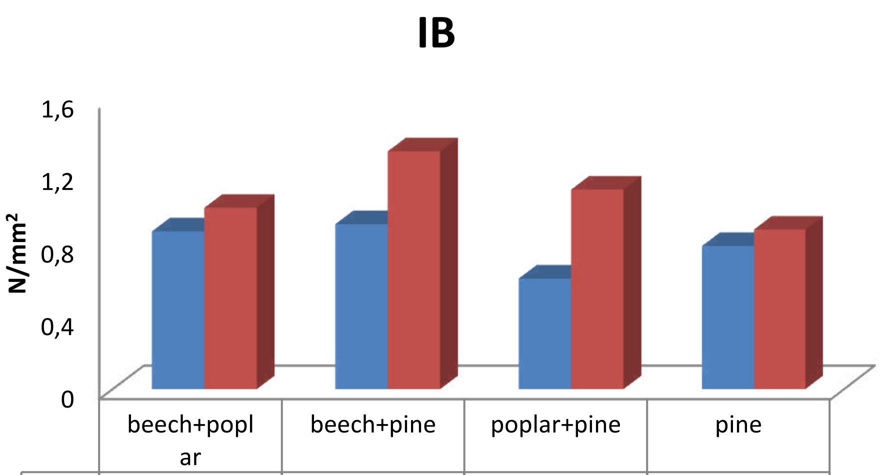
	beech+popl ar	beech+pine	poplar+pine	pine
650	6839	6951	6769	6043
720	7031	8174	7004	7306

Figure 52. The effect of density and different wood species mixture on MOE (n=6)

5.3.3 Internal Bond

Figure 53 demonstrates that higher internal bond values were achieved at 720 kg/m^3. It means with increasing density, internal bond is improved. These results coincide with values reported by Kajita 1987, Canadido et al. 1990. Sumardi et al. 2007 and Malanit et al. 2010 determined the effect of board density and layer structure on the mechanical properties of bamboo oriented strandboard and revealed that IB was greatly affected by density and exhibited a similar trend in bending properties as function of density.

In addition to MOR and MOE, the pine panels showed lower IB compared to panels made from beech and poplar. Panels C and D made with a mixture of beech and pine strands reached higher IB value at both densities compared to other combinations that are at least 45 and 31 % higher than pure pine, and poplar and pine strands (at 720 kg/m^3). It is commonly accepted that density has an undeniable effect on mechanical properties and also IB and it appears the higher density of beech and pine species compared to poplar support these conclusions. Therefore, the properties of OSB made of beech and pine improved compare to pure pine OSB or poplar / pine OSB.



	beech+poplar	beech+pine	poplar+pine	pine
650	0,87	0,91	0,61	0,79
720	1	1,31	1,1	0,88

Figure 53. Average values of internal bond strength (n=18)

5.3.4 Thickness Swelling after 24h

Figure 54 illustrates the thickness swelling (TS) between different treatments. This figure showed that pure pine panels and panels made with mixtures of beech and pine had almost the same TS which is around 10 % higher than maximum TS in EN317 (20 % for OSB panel type 2). Dimension instability, especially TS in present of water or moisture is the main disadvantage of OSB (Young et al. 2009, Houts et al. 2006). In this study OSB were made in the lab without the addition of wax or other additives. The use of wax could be a solution for reaching the standard value.

Interestingly, with regard to physical properties, panels made with a mixture of hardwood species recorded low TS values. Beech and poplar panels showed only one third of EN300 standards allowed value for TS at 720 kg/m^3. As discussed in a previous study (Akrami et al. 2014 a), panels made from pure beech strands showed the same trend and as density increased the TS value decreased.

Panels manufactured with higher compression levels during hot pressing show a higher tendency to springback and swell to initial thickness before pressing. Because of high density of beech strands compared to poplar, these strands have received lower densification during the manufacturing of the panel in the hot press. On the other hand, the higher spring back of poplar strands might be masked by the beech strands. This could be the main reason for lower TS compared to other combinations. This trend was even observed at higher density (720 kg/m^3) because of higher amount of strands and lower compression to reach the final panel thickness.

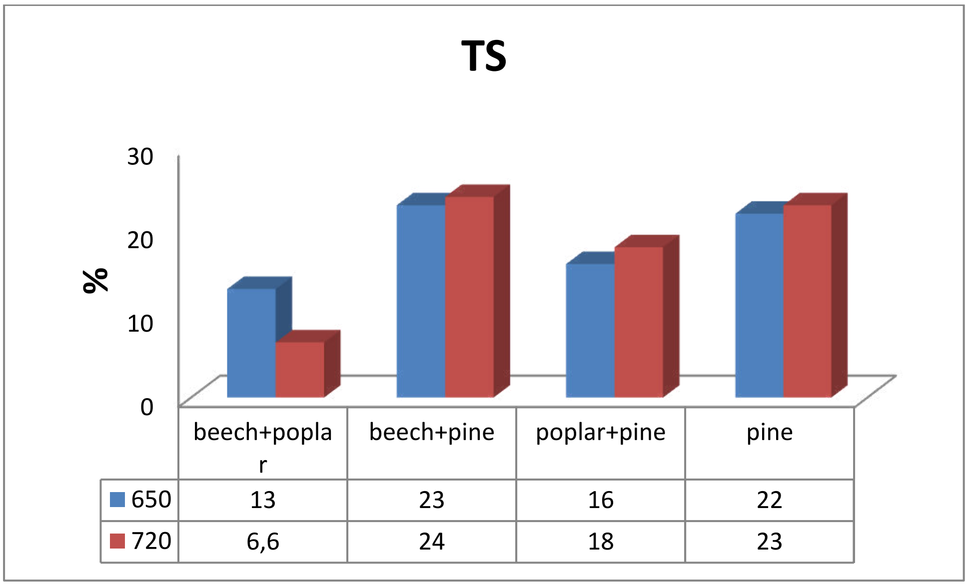


Figure 54. Average values of thickness swelling (n=18)

5.4 Veneer Densification

Laleicke 2012 worked on beech and poplar veneers at two temperature levels (180 and 220 °C) with and without urea formaldehyde resin to determine the differences between species due to compaction behavior as part of this project. The aim of this part of the study was to identify and characterize compaction behavior of poplar and beech during and after the hot press. Measurements and results that were obtained in this work do not indicate that beech or poplar would be unsuitable. Rather, it is clear that both species behave differently during and after compression. In conclusion it could be confirmed that the difference in density has an influence on the stress strain behavior of both species. Beech is more difficult to compress and requires higher pressure. Poplar in contrast is easy to compress at low pressures, causing low stress in the material.

The fixation-effect of UF-resin could be demonstrated in the stress-strain behavior. Additionally, the moisture content of the mat was increased due to the resin application, resulting in a longer elastic phase, making the wood more adaptive to stress during the compression.

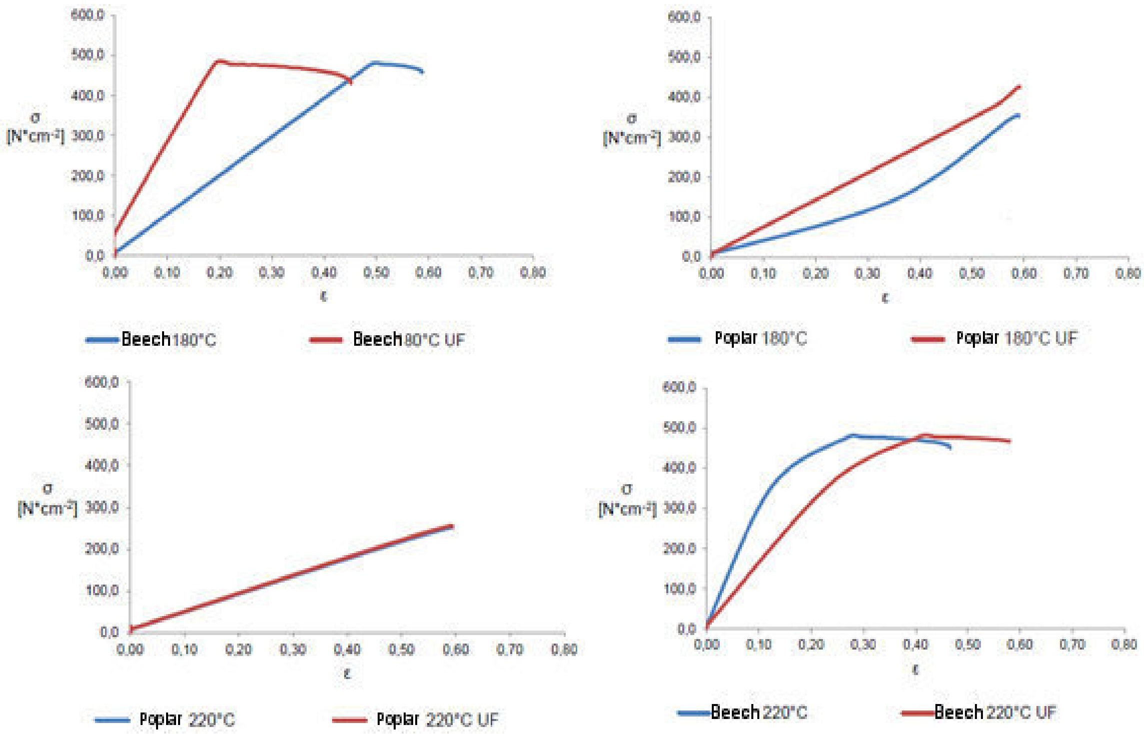


Figure 55. Stress strain diagrams of the densification experiments

The other aspect of densification was measuring springback after hot pressing that highly related to applied pressure during densification in hot press. In this project, poplar (400 kg/m^3) and beech (600 kg/m^3) at two temperatures (180 and 220 °C) were densified.

Two factors such as wood species and the influence of different press temperature on springback were recorded. Because of lower density of poplar compared to beech, poplar veneer endured higher pressure to reach the final thickness.

The results indicated that springback for both species was lower at 220 °C compared to 180 °C. The results also showed the influence of species on springback was different at different press temperature. For instance, poplar veneer showed higher springback and swelling at 180 and 220 °C compared to beech.

Veneer with UF resin showed different results compared to veneer without resin. The springback of beech is lower at 220 °c, while poplar veneer showed higher springback at 220 °C compared to 180 °C.

5.5 VOC Emission

In Europe, demand for wooden buildings has increased in recent years. Oriented strand board (OSB) has become the primary and the best option for engineering wood based panels. The conventional raw material in Europe for OSB is pine and spruce. Today, almost all OSB producers in Europe rely on these two softwood species for production. This places tremendous pressure on softwood forests in Europe and the ability to supply raw materials for wood based panels industries is a major challenge for the future. On the other hand, there has been a growing trend towards stricter regulations for air quality and a decrease in the parameters that lead to air pollution. Several organizations and institutes are currently focused on these concerns in an effort to control emissions from wood products. As OSB is a structural material for the building sector, it has a direct effect on human health and monitoring its impact on human life seems necessary. The important volatile organic compounds (VOC) emission from Scot pine (*Pinus sylvestris L.*) OSB is terpene and aldehyde. Makowski and Ohlmeyer (2006) investigated the impact of drying temperature and pressing time factor on VOC emission from OSB made of Scot pine. They observed that terpene emission was lowered with evaluated pressing time, whereas the formation of volatile aldehydes was accelerated. Finding a suitable alternative raw material for OSB that could reduce the environmental concern is a priority. Hardwood species that are available in almost all European countries could be offer the important key.

The emission factors for TVOC and acetic acid from the OSB panels as well as solid wood samples are shown in Fig. 56 through 63. TVOC for all samples decreased during the first 14 days although obvious differences are clear between panels and solid woods and also among beech and poplar species. For example, for solid beech, terpenes were around 180 µg m^{-3} but for solid poplar were 50 µg m^{-3}. In addition, the decrease of terpenes for beech OSB was from 150 to 180 µg m^{-3}, however for poplar OSB was from 100 to 45 µg m^{-3}. The same trend for acetic acid was observed. The highest acetic acid belongs to solid beech wood, 700 µg m^{-3}. This amount rapidly decreased to 180 µg m^{-3} after first 14 days.

As expected, beech species showed higher VOC emission compared to poplar, especially acetic acid emission, in both cases of panel or solid wood samples. Another import issue was lower VOC emission of OSB samples for both beech and poplar species compared to solid woods. A VOC emission comparison between beech and poplar to pine species shows that these species have a lower VOC emission. Makowski and Ohlmeyer 2005, studied VOC emission of OSB made from pine (*Pinus sylvestris L*) and noticed that terpene decreased from 5900 to 2000 µg m^{-3} after 14 days. Wike et al. 2013 measured VOC emission from OSB boards and their assessment according to the AgBB scheme. They used OSB purchased from "Do-it-yourself" stores and tested VOC emissions by means of emission test chambers. They found that TVOC of these panels was above 1000 µg m^{-3}. Four boards from three manufacturers would not meet the requirements of the German AgBB (Committee for Health Evaluation of Building Products) scheme

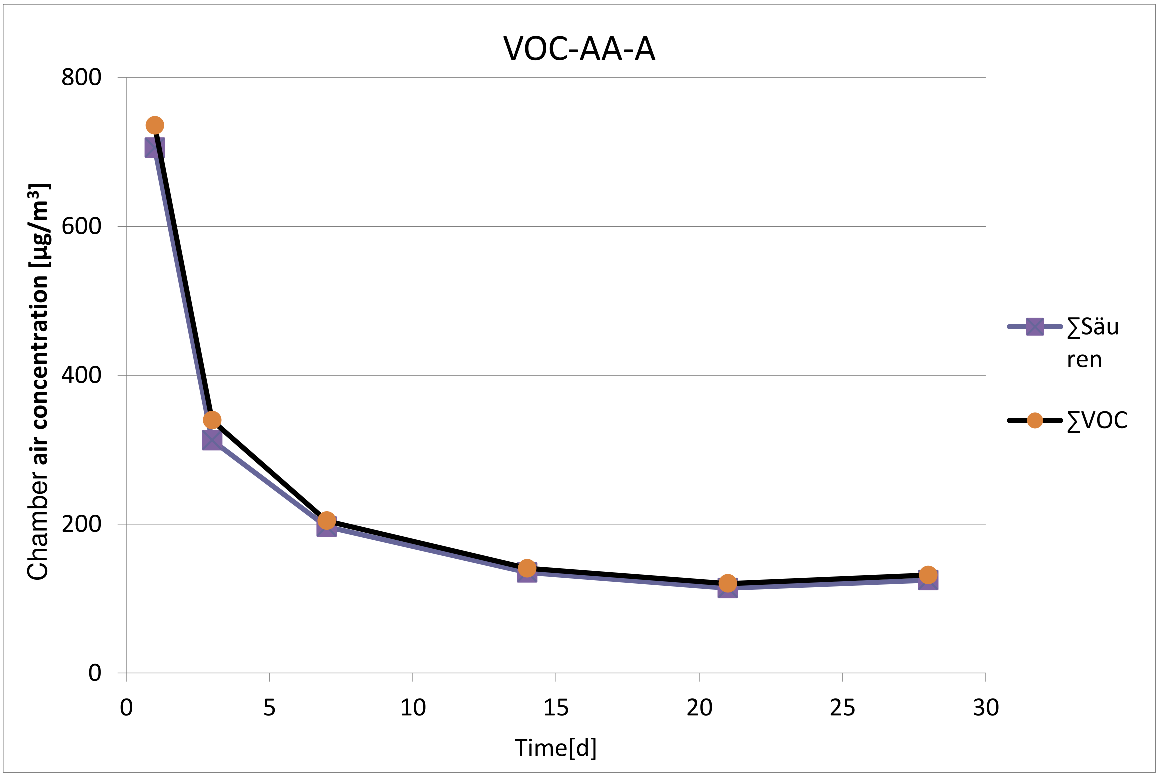


Figure 56. Total emission rate of solid beech during 28 days of testing

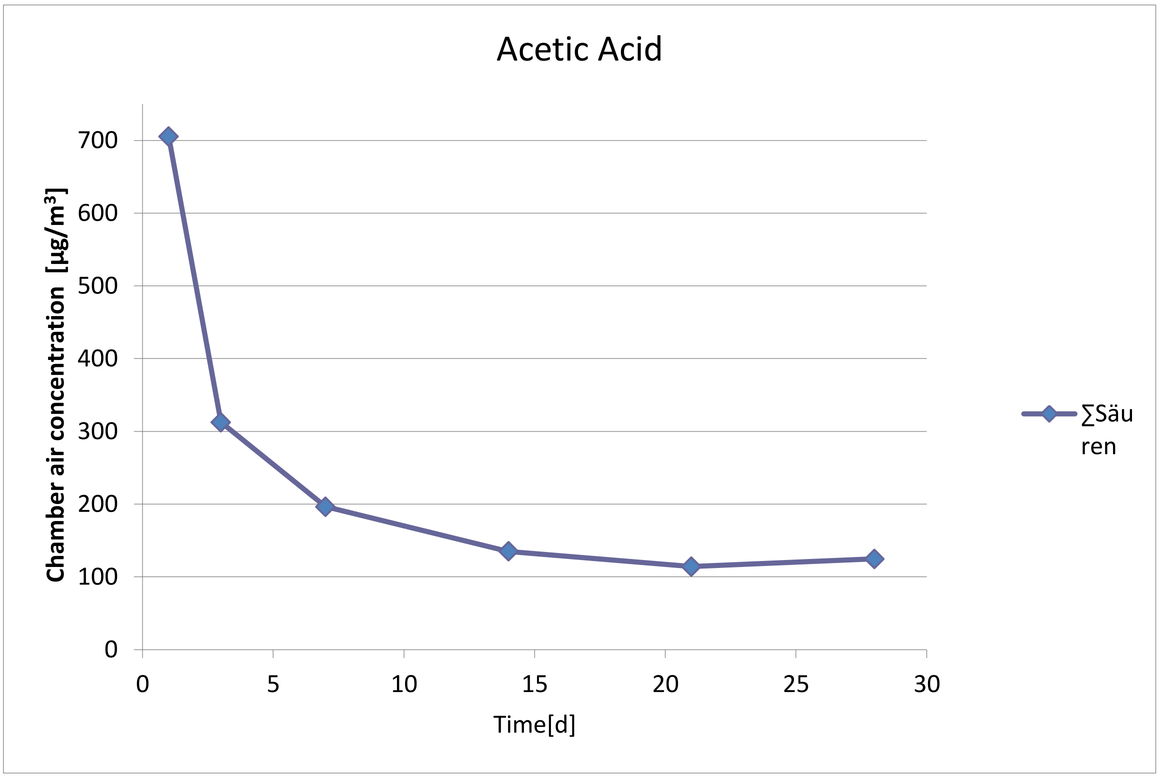


Figure 57. Acetic acid emission rate of solid beech during 28 days of testing

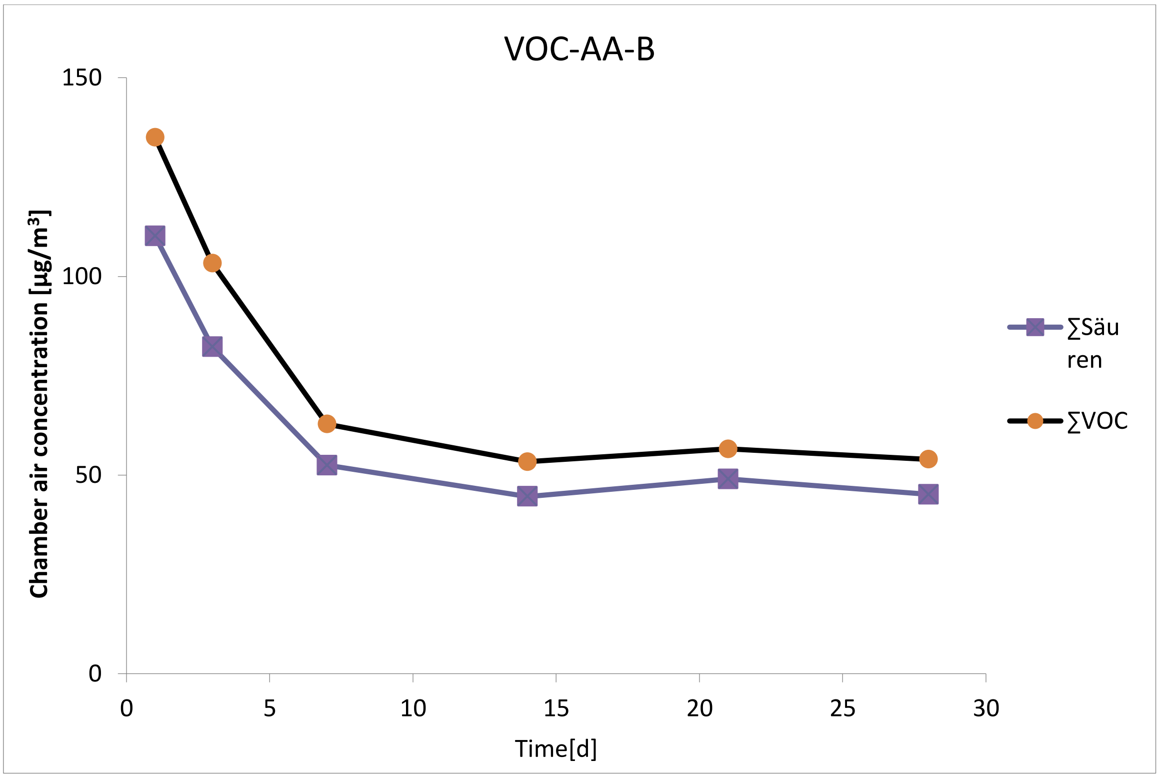


Figure 58. Total emission rate of solid poplar during 28 days of testing

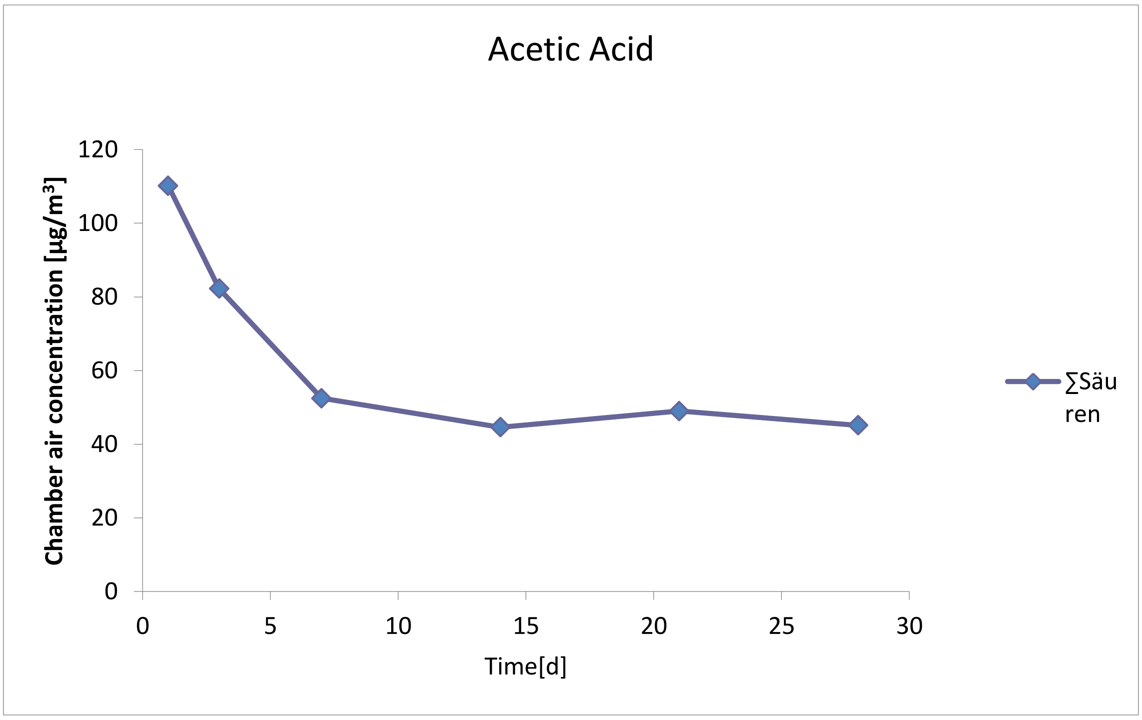


Figure 59. Acetic acid emission rate of solid poplar during 28 days of testing

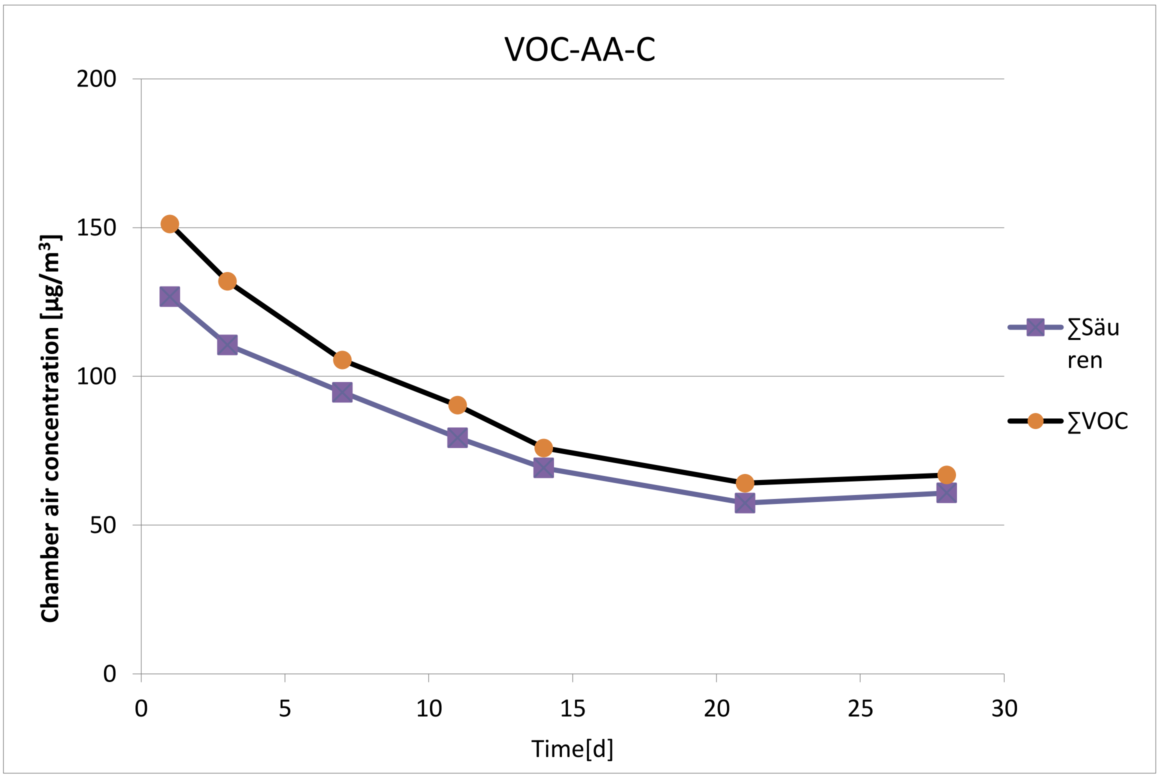


Figure 60. Total emission rate of beech OSB during 28 days of testing

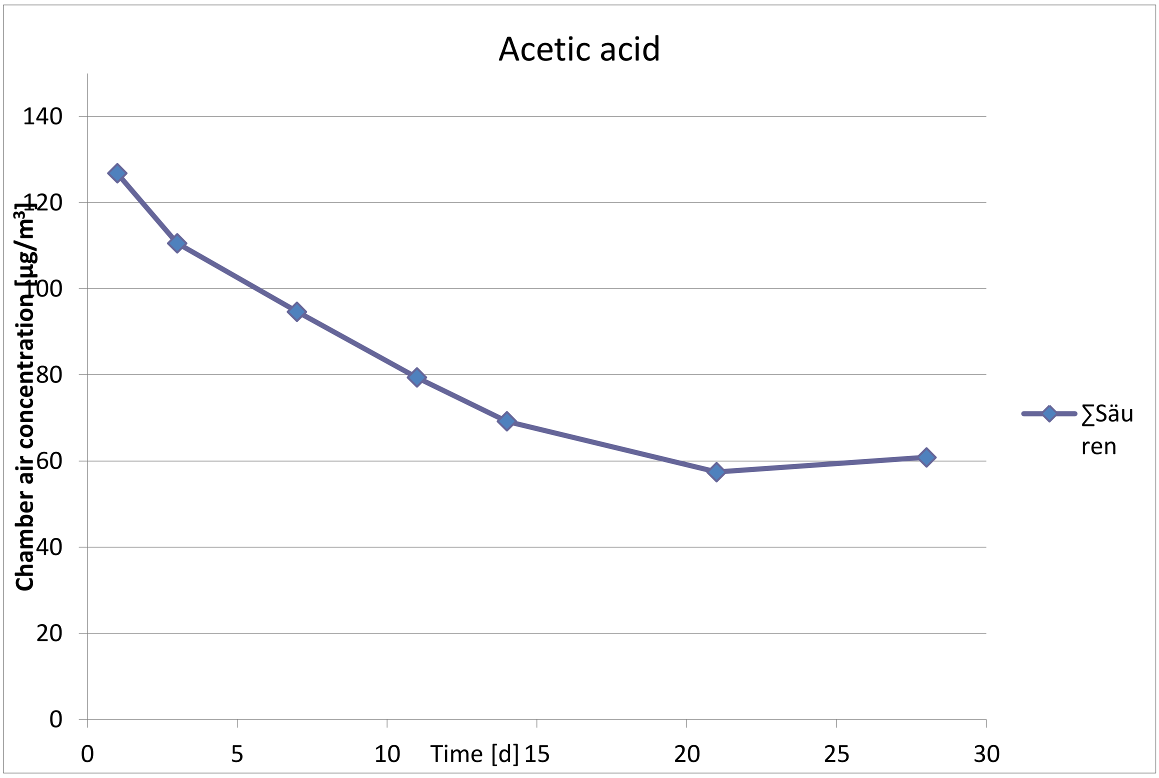


Figure 61. Acetic acid emission rate of beech OSB during 28 days of testing

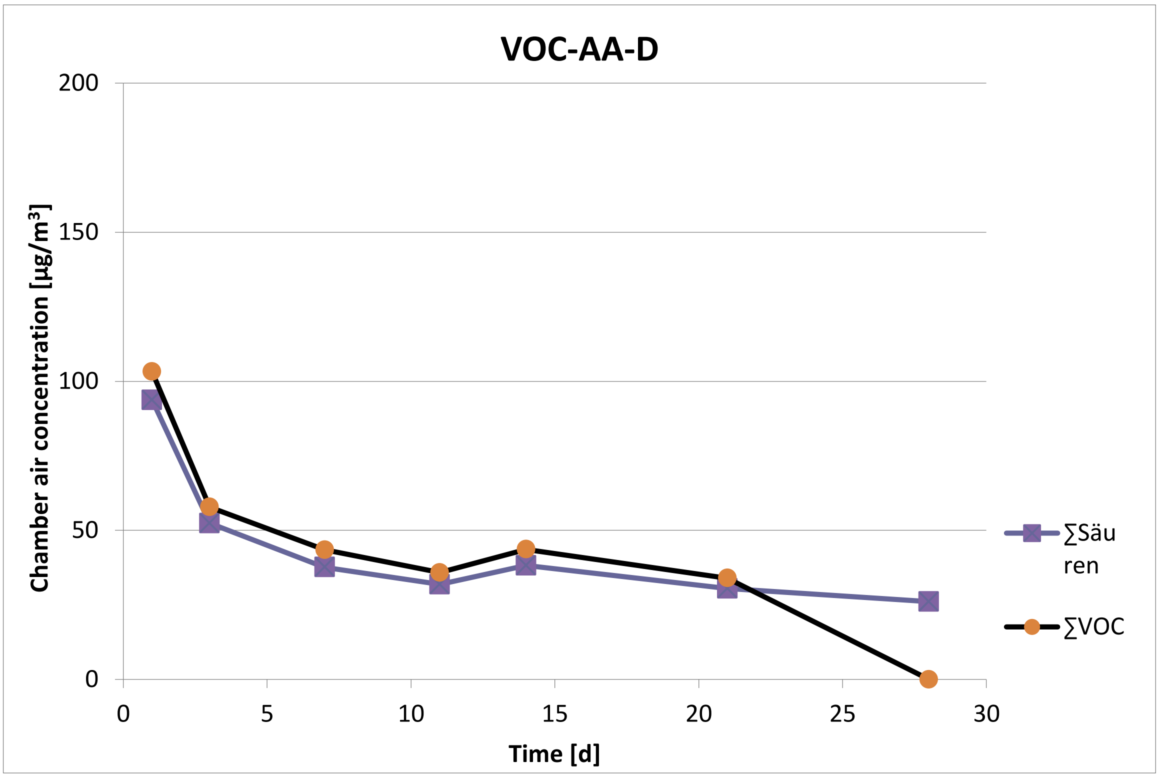


Figure 62. Total emission rate of poplar OSB during 28 days of testing

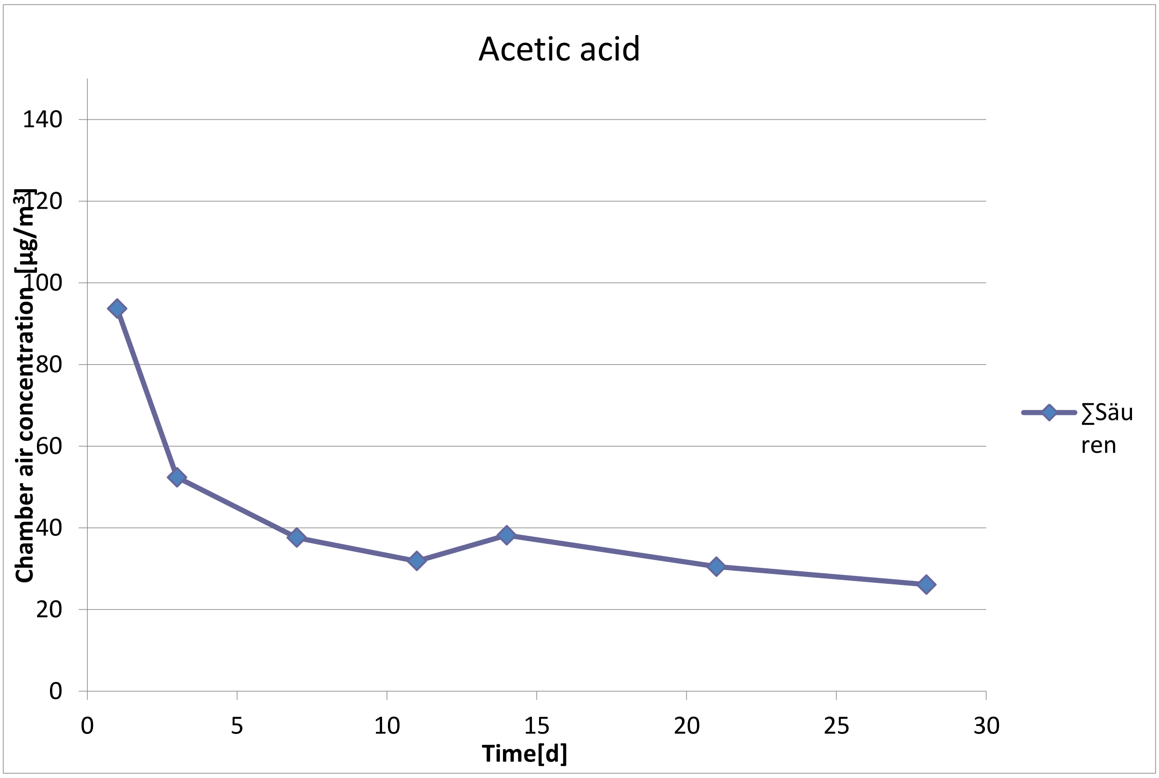


Figure 63. Acetic acid emission rate of poplar OSB during 28 days of testing

6 Conclusions & Recommendation

The aim of this study was to determine the physical and mechanical properties of OSB made from different combinations of European beech and poplar strands, i.e. varied face/core ratios and two different densities.

The results indicate that based on the availability of beech and poplar in Europe and given the lower VOC emission levels of beech and poplar OSB compared to pine based OSB, there is a potential for a new raw materials market for OSB. All technical properties of these panels fulfilled the minimum requirements for OSB type 2 of EN300 standards, with exception of panels made of 75 % poplar strands in the core layer. In general, panels with different face/core ratios show better properties compared to OSB manufactured from 100 % beech and poplar strands. Therefore, a mixture of these two low and high density hardwood species could possibly be used to introduce a new competitive product on the conventional OSB market and reduce the pressure to use softwoods, especially pine and spruce. As for the physical properties, thickness swelling and dimensional instability are important disadvantages of OSB. However, the results of this project showed that the thickness swelling values were acceptable compared to EN300 standards that related: (1) to pMDI as water resistance glue and (2) also different panel designs and combinations to restrain this effect. In comparison, OSB made of beech strands in the core layers has higher MOR, MOE and IB values and also showed lower thickness swelling compared to poplar strands based core panels.

This study also examined the use of fine core material and its effect on physical and mechanical properties of European beech and poplar OSB. Using beech and poplar as raw materials for the OSB market is rather new in Europe and little is known about the influence of fines material in the core layer on OSB properties. Despite these limitations, the findings of this project show that using hardwoods such as beech and poplar combined with board core layers consisting of up to 30 % of fines material could introduce a different type of OSB to the market. The mechanical properties such as MOR and MOE and also internal bond reach the minimum requirement for OSB type 2 (EN300). In addition, panels made with 100 % poplar and also panels made with 50 % fines in the core layer showed at least two fold MOR and MOE more than EN300 standards for OSB type 2. In the case of physical properties, an increase in fines content in the core layer of up to 50 % saw a decrease in thickness swelling after 24h. The tests proved that not only could fines material be introduced as an effective parameter to reduce OSB production costs, but it also can improve some practical OSB properties. The usage of fines material in the core layer has no negative influence on bending strength and improves the internal bond strength. In addition, the fines material has a positive effect on reducing the common problem of thickness swelling in OSB panels.

The third scientific attempt was to discover the possibility of using a mixture of European beech and poplar as raw materials for OSB manufacturing. Although changing producer behavior is not so easy, nevertheless this study has been trying to encourage them to use a new/suitable alternative material to replace into current production. This study examines experimental OSB made with a mixture of beech and poplar strands and compared to the pine one as conventional OSB in Europe. The results of this project demonstrated that using beech and poplar as a mixture could meet the minimum requirement for OSB type 2 as well as pure beech or poplar OSB. In addition, the mechanical properties results illustrated a combination of pine with beech or poplar strands could present better properties compare to pure pine strand based panels. Therefore, producers would be wise to think about substituting current raw materials with hardwood species. Doing so could reduce their concerns regarding future raw materials supply and help to reduce pressure on Europe's softwood forests. Regarding physical properties, mixing beech and poplar strands showed that there is the potential to reduce thickness swelling after 24h which is an important achievement for OSB. Furthermore, with regard to technical properties, using low quality and small diameter beech and poplar trees could be an essential economical aspect as it would reduce production costs.

Among all treatments, designs, and board combinations, an overall look thorough all boards addressed to find the best board modification to achieve all or at least maximum requirement such as MOR, MOE, IB, and TS for OSB manufacturing regarding the species which used in this study.

Among panels made by normal beech and poplar strands in face and core layers for different face-core ratios, panels made with 40 % poplar in the core layer shows improved physical and mechanical properties. Although 100 % beech OSB showed slightly higher MOE (6317 N/mm^2) compared to these panels (6039 N/mm^2). In general, panels made with beech in the face layers and 40 % normal poplar strands showed the best properties.

Among panels made with a mixture of normal beech-poplar strands and beech-pine or poplar-pine, a mixture of beech and poplar strands showed the best properties. Panels made with a mixture of beech and pine also showed a very good internal bond, but the comparison in thickness swelling (40 % lower than beech-pine panels) showed that a mixture of beech and poplar strands as the best candidate in this group.

Poplar strand board with 30 % fine poplar in the core layer showed the best properties, especially regarding mechanical properties among the panels made with fines material. However, 10 % thickness swelling of panels made with normal beech in the face layer and 50 % fine poplar in the core layer was the best panel regarding physical properties, but 30 % fine core poplar panels thickness swelling showed 30 % lower TS compared to EN standards. Table 12 showed the different physical and mechanical properties between the best OSB combinations of different groups.

Table 12. Comparison properties between different OSB combinations

Treatment	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	TS (%)
30-40-30% beech+poplar+ beech	54	6039	0.8	10
mixture of beech+poplar	61.7	6839	0.87	13
100% poplar+30% fine core	71.27	9882	0.93	14

In terms of veneer densification, the results indicated that despite the higher density of beech compared to conventional raw materials, density would not be a significant factor for limiting the usage of beech species. Although beech showed lower densification compared to poplar, the board properties showed acceptable properties in comparison with other board designs.

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Akrami A[1], Barbu M.C, Frühwald A. 2014. Characterization of properties of oriented strand boards from beech and poplar. European Journal of Wood and Wood Products. 72: 393-398.

Akrami A[1], Frühwald A, Barbu M.C. 2014. The effect of fine strands in core layer on physical and mechanical properties of oriented strands boards (OSB) made of beech (Fagus sylvatica) and poplar (Populus tremula). European Journal of Wood and Wood Products. 72: 521-525.

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[1] Research design, experimental works (boards manufacturing & board properties testing), literature review and also drafting and writing all papers have been done by Ali Akrami.
Prof. Dr. Arno Frühwald and Prof. Dr. Marius C. Barbu contributed to the ideas, discussion of results, and checking of manuscript.

Characterization of Properties of Oriented Strand Boards from Beech and Poplar (2014)

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ORIGINAL

Characterization of properties of oriented strand boards from beech and poplar

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Abstract The aim of this study was to evaluate the possibility of using European beech and poplar species to manufacture oriented strand boards (OSB). Beech and poplar strands with three different combinations of face/core ratios at densities of 650 and 720 kg/m^3 were examined. Poly methylene diphenyl diisocyanate glue at 5 % was used with press conditions of 180 °C and 240 s. Findings showed that with increasing density the physical and mechanical properties of the different OSB combinations generally improved. Panels made of 60 % beech in face layers showed higher modulus of rupture and modulus of elasticity. Internal bond strength rose as the amount of beech strands in the core layer increased. Panels with 75 % beech strands in the core layer showed the maximum internal bond strength at 720 kg/m^3. It was also observed that increasing the amount of beech in the core layer from 40 to 75 % decreased thickness swelling at both densities.

1 Introduction

Oriented strand boards (OSB) application has grown remarkably in recent years making it an important wood-based panel product. OSB plays a significant role in the building sector especially in North America. Although initial attempts to produce OSB were made back in the 1980s, this new product could compete with those on the plywood market due to a shortage of best quality logs in diameter, environmental concerns and of course the cost of plywood manufacturing. OSB has firmly established its market place in North America and since 2000 has penetrated the European market for structural applications. OSB is widely used for various applications such as wall and roof sheathing, flooring, packaging and I-joints. It is also used in other structural applications such as furniture, reels pallets, boxes, trailer liners and recreational vehicle flooring (Hiziroglu 2006; Irle et al. 2013). OSB has captured more than half of the structural panel market in the last two decades (Barbu 2012). Reviewing the history of OSB clearly shows that it went through several developments before it successfully became part of a competitive stable market. A key factor influencing future market volume is the shortage of suitable raw materials. One example already mentioned in this context is plywood. The shortage of large diameter logs grown under optimum conditions used to produce high-quality plywood necessitated research into new market opportunities for a wood-based product with the same or even better properties than plywood. OSB has been found to be a very good solution around 30 years ago.

A sustainable OSB market is very closely linked to the supply of raw materials. OSB is an engineered product consisting of thin strands of wood, 8–15 cm in length, 10–30 mm in width and 0.7–1 mm in thickness. In contrast to plywood, the supply of raw materials for the OSB market is quite vast, given, for example, the abundance of low quality logs and species with lower diameters. Nevertheless, it is important to select suitable species to produce OSB so that good practical properties as well as feasible large volumes can be achieved. Today almost all

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OSB lines in Europe use softwoods as raw materials especially pine and spruce. However, due to the large amount of volatile extractives, volatile organic compound (VOC) is a major concern associated with products derived from pines.

The use of hardwoods as raw material for OSB is quite new in Europe, and currently no OSB panels are made from 100 % hardwood species. Previous research based on the possibility of using certain hardwoods together with pine exists, but the study was not extensive (Beck et al. 2009). Han et al. (2007) examined the influence of fines content and panel density on properties of small-diameter mixed hardwoods such as oak, cottonwood and hackberry. Two important wood species which are available in Europe are beech (*Fagus silvatica*) and poplar (*Populus tremula*). Most small diameter beech roundwood is used in the energy sector, although it could be a very good opportunity as value added material for OSB. In Europe, poplar plantations cover a total area of 950,000 hectares. France, Turkey, Italy, Hungary, Germany and Romania host the largest amount of poplar (Coaloa and Nervo 2011). There is great potential for OSB manufacturing in these regions. Initial industrial trials are underway and new factories are being planned (Anonymous 2013). The aim of this study was to evaluate the possibility of using European beech and poplar as two important wood species in Europe to develop OSB with high mechanical properties for the building sector.

2 Materials and methods

European beech and poplar trees, with an average DHB of 20–40 cm were harvested near Hamburg, Germany. Logs were cut into 120 cm long sections and debarked by hand. The wood densities were 0.36–0.4 and 0.7 g/cm^3 for poplar and beech, respectively. The strands were produced with a Pallmann knife ring flaker (Pallmann Company, Zweibrücken, Germany). The average strand sizes were 0.7 mm in thickness, 125 mm in length and 20–40 mm in width. Strands were screened and sorted before being further treated.

The target moisture content was 5 and 10 % based on oven-dry weight for core and surface layers, respectively. The adhesive applied was methylene diphenyl diisocyanate (pMDI) from Huntsman, Belgium. The strands were blended with 5 % pMDI, and no wax or other additives were used. Three layers of manually formed mats with strands of core layer perpendicular to the surface layers with 16 mm nominal thickness were manufactured in a Siempelkamp laboratory press. The mats were compressed to a final thickness for 240 s at a temperature of 180 °C. Two target densities and three different face/core ratios (25/75–50/50–60/40 %) were selected. The different combinations are presented in Table 1. Two replicates were used for each combination, and a total of 32 boards were manufactured.

After pressing of the panels, each board was cooled to room temperature and then trimmed from 600 by 550 mm to 490 by 410 mm to remove the low-density edges. Prior to testing, the panels were conditioned at relative air humidity (RH) of 65 % and temperature of 20 °C for 2 weeks. Figure 1 shows un-pressed mat.

Modulus of elasticity (MOE), modulus of rupture (MOR), internal bond (IB) strength, thickness swelling after 24 h (TS 24 h) were determined and compared to the EN 300 standard. Three samples (370 by 50 mm) from each panel were used to test bending strength. To test IB strength, nine 50 by 50 mm specimens were cut from each panel. Prior to testing of IB according to EN 319, three samples were selected to analyze density profiles in the thickness

Table 1 Characteristics of the OSB

Treatment	Panel type	Density	Face/core/face ratio (%)
A	Beech	650	100
B	Beech	720	100
C	Poplar	650	100
P	Poplar	720	100
K	b + p + b	650	30–40–30
F	b + p + b	720	30–40–30
D	b + p + b	650	25–50–25
E	b + p + b	720	25–50–25
L	b + p + b	650	12.5–75–12.5
G	b + p + b	720	12.5–75–12.5
M	p + b + p	650	30–40–30
J	p + b + p	720	30–40–30
H	p + b + p	650	25–50–25
I	p + b + p	720	25–50–25
O	p + b + p	650	12.5–75–12.5
N	p + b + p	720	12.5–75–12.5

B Beech, *P* Poplar

Fig. 1 Hand formed beech mat (*left*) and poplar mat (*right*)

direction using X-ray densitometry (Itrax Woodscanner, Cox Analytical System) based on the relationship of X-ray and density. Nine 50 by 50 by 16 mm samples were cut for thickness swelling test (in total 18 samples for each treatment) according to EN 317. Average thickness was measured in the center of each sample. Later, the samples were submerged into water at 20 °C for 24 h. Then, the specimens were dripped and wiped clean of any surface water. The thickness of the specimens was measured with a digital caliper of 0.01 mm precision. For the measurement of MOR and MOE values according to EN 310, a Zwick/Roell Z050 universal test device was used. When testing, the loading mechanism was operated with a velocity of 10 mm/min. The IB strength test was performed using a universal testing machine as well (Losenhausenwerk).

3 Results and discussion

The average and standard deviation of values of MOR and MOE for the major board axis and IB are given in Table 2 and the thickness swelling after 24 h of produced panels are also listed in the same Table. In general, with increasing density all mechanical properties and also IB increased, except for MOE and IB for panels J and G, respectively. These results are similar to those obtained by Chen et al. (2010); Sumardi et al. (2007); Han et al. (2006); Nishimura et al. (2001) and Vital et al. (1974). The finding also indicates that TS increases with density, but an inverse effect was observed on pure beech panels and panels with core layer made of beech strands. It is commonly accepted that TS values have a direct correlation with density and will increase when the panel density increases (Yale 1956; Gatchell et al. 1966; Roffael and Rauch 1972; Wu and Piao 1999), yet some studies have obtained contradictory results. Liu and McNatt (1991) examined thickness swelling and density variation in aspen flakeboards and conditioned these panels at 80 % RH for 71 days and found no clear relation between density and TS. However, increases in mechanical strength with increases in density can be sufficient to balance increased swelling tendency (Lehmann 1960), and high density can increase the efficiency of resin usage, therefore reducing thickness swelling (Clad 1967).

Table 2 Physical and mechanical properties of OSB boards

Panel	Density (g/cm^3)	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	TS (%)
A	0.63 (0.02)	35.8 (4.3)	6,320 (200)	0.4 (0.13)	16 (3)
B	0.73 (0.01)	52.5 (5.4)	6,890 (331)	0.7 (0.08)	12 (2)
C	0.66 (0.03)	23.7 (2.8)	4,980 (212)	0.3 (0.1)	19 (3)
P	0.71 (0.04)	42.4 (6.5)	5,440 (696)	0.6 (0.13)	23 (3)
K	0.62 (0.01)	54 (6.3)	6,090 (458)	0.84 (0.14)	10 (1)
F	0.73 (0.03)	59 (1.7)	7,070 (633)	0.99 (0.19)	11 (4)
D	0.66 (0.05)	39.5 (5.1)	4,960 (211)	0.53 (0.18)	12 (3)
E	0.71 (0.03)	49.3 (6.3)	5,840 (100)	0.56 (0.08)	20 (3)
L	0.64 (0.05)	34.7 (8.3)	4,690 (219)	0.50 (0.12)	15 (2)
G	0.7 (0.04)	41.2 (3.6)	5,630 (684)	0.27 (0.03)	25 (4)
M	0.64 (0.03)	42 (3.2)	5,970 (137)	0.53 (0.12)	16 (3)
J	0.71 (0.06)	47.1 (4.8)	5,490 (563)	0.55 (0.06)	14 (4)
H	0.63 (0.02)	47.8 (4.17)	5,310 (254)	0.63 (0.14)	13 (3)
I	0.74 (0.04)	50 (4.4)	6,050 (460)	0.70 (0.19)	9 (4)
0	0.65 (0.03)	39 (6.07)	4,420 (758)	0.70 (0.25)	11 (3)
N	0.74 (0.02)	42.5 (4.2)	5,330 (447)	0.81 (0.2)	6 (2)

Standard deviation in parentheses

MOR modulus of rupture, *MOE* modulus of elasticity, *IB* internal bond, *TS* thickness swelling after 24 h

Table 2 also illustrates that all properties meet the EN standard of minimum requirement for OSB Type 2 (EN 300) with the exceptions of IB and TS for panel G and also TS for panel P.

3.1 Vertical density profile

In general, high density face and low density core layers are a schematic vertical density profile (VDP) for OSB. Figure 2 shows that the average VDP of beech core panels is lower than that of poplar core boards, and it is related to higher density of beech strands. The formation of such a profile is a combination of the gradients temperature, moisture content and pressure in strands during hot pressing (Chen et al. 2010). The influence of VDP on OSB properties has been the topic of several previous research studies (Xu 2007; Gu et al. 2005; Jin et al. 2009), and this research confirmed these results because of higher amount of beech panel properties.

3.2 Bending strength (MOR)

In general, an increasing core layer thickness or, on the other hand, a decreasing face thickness from 60 to 25 % of the overall panel thickness leads to a decrease in bending strength, although the correlations between decreasing MOR and MOE in panels made of beech were not as strong as in panels made of poplar core layer.

In OSB with a core made of beech strands, as the face thickness decreased from 60 to 50 %, the MOR and MOE slightly increased for both densities types. When the face thickness was lowered to 25 %, the bending strength continued to decrease (Fig. 3).

While the lowest MOR value (23.77 N/mm^2) was measured for panels produced only from poplar strands (panel C) with 650 kg/m^3 density, the highest value (59 N/mm^2) was obtained at 720 kg/m^3 density and 60 % beech strands in face layer (panel K) which is almost three times higher than the standard requirements of EN 300 for OSB type 2 (Fig. 3).

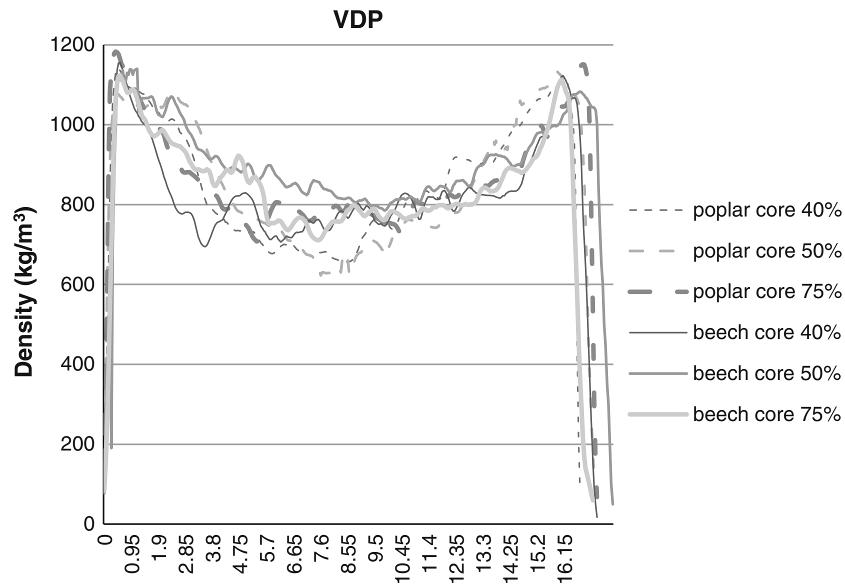
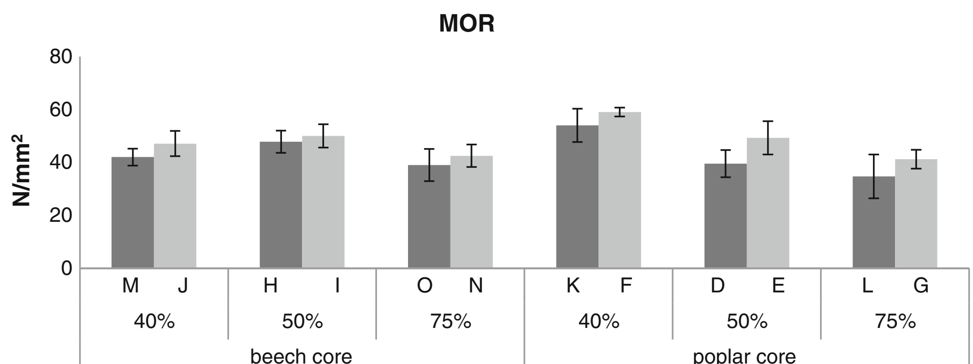
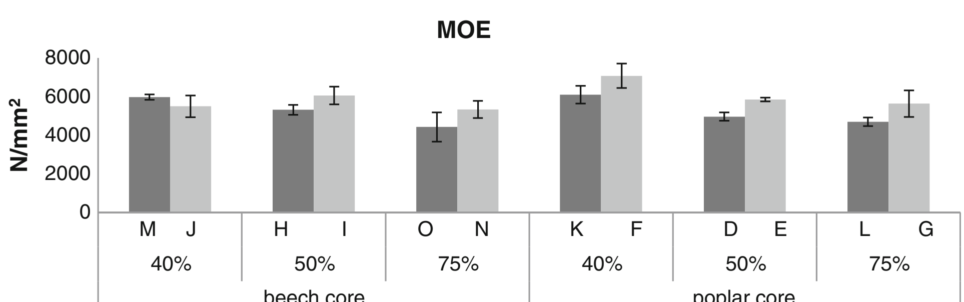


Fig. 2 Vertical density distribution of beech and poplar core strands made of OSB at 650 kg/m^3



	M J 40% (beech core)	H I 50% (beech core)	O N 75% (beech core)	K F 40% (poplar core)	D E 50% (poplar core)	L G 75% (poplar core)
650	42	47.8	39	54	39.5	34.7
720	47.1	50	42.5	59	49.3	41.2

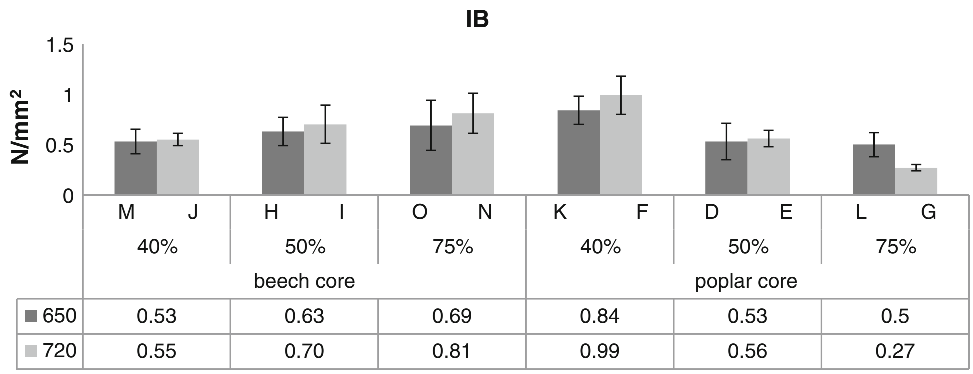
Fig. 3 Average MOR of beech and poplar strands based core 16 mm OSB



	M J 40% (beech core)	H I 50% (beech core)	O N 75% (beech core)	K F 40% (poplar core)	D E 50% (poplar core)	L G 75% (poplar core)
650	5970	5310	4420	6090	4960	4690
720	5490	6050	5330	7070	5840	5630

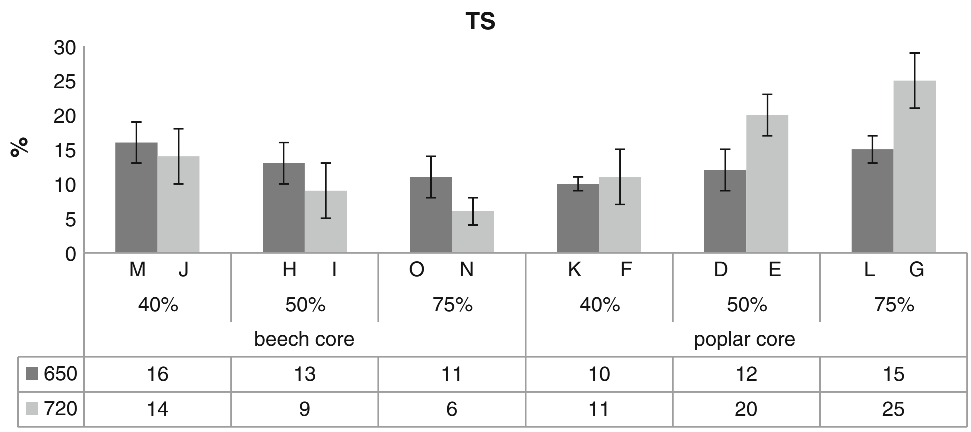
Fig. 4 Average MOE of beech and poplar strands core 16 mm OSB

This study observed the same trend in highest MOE for panels manufactured from 60 % beech strands in faces. The highest and lowest values of MOE were 7,066 and 4,415 N/mm^2 for panels F and N, respectively (Fig. 4). These results indicate that face layer plays an important role in bending strength, and that thickness of the face layer as well as alignment could improve the MOR and MOE.



	M J 40%	H I 50%	O N 75%	K F 40%	D E 50%	L G 75%
	beech core			poplar core		
650	0.53	0.63	0.69	0.84	0.53	0.5
720	0.55	0.70	0.81	0.99	0.56	0.27

Fig. 5 Average IB of beech and poplar strands based core 16 mm OSB



	M J 40%	H I 50%	O N 75%	K F 40%	D E 50%	L G 75%
	beech core			poplar core		
650	16	13	11	10	12	15
720	14	9	6	11	20	25

Fig. 6 Average TS of beech and poplar strands based core 16 mm OSB

3.3 Internal bond

The results showed that the IB values of the test samples varied between 0.3 and 1.0 N/mm^2. Mean IB strength of all boards was higher than the minimum requirements for OSB type 2 which is 0.3 N/mm^2 (EN300), except panel G. In addition, IB increases with the density which corresponded to previous findings in research studies such as Dai et al. (2008) and Jin et al. (2009).

When the amount of poplar strands was increased in the core layer from 40 to 75 %, the IB decreased from 0.99 to 0.27 N/mm^2 (Fig. 5). By increasing the amount of beech strands in the core layer, the adverse trend was observed. 0.81 N/mm^2 was the maximum IB reached by panels with 75 % beech strands in the core at 720 kg/m^3 (panel N). Due to the higher density of beech compared to poplar, it appears that the moisture transfer from surface layers into the core has a positive effect in the presence of heat and resulted in plasticization behavior in the core layer which increased the flexibility of beech strands in contact with pMDI during the hot mat consolidation. In cases with a higher amount of poplar strands in the core layer, the internal gas pressure during hot pressing made these glue bondages break, probable because of the lower density and weakness of wood-pMDI bond. This IB decreasing rate for panels with 720 kg/m^3 density was clearly observed because of the higher amount of poplar strands and the increased internal gas pressure during hot pressing.

3.4 Thickness swelling after 24 h (TS 24 h)

It was found that the TS rate after the sample had been kept in water for 24 h at 20 °C ranged from 6 to 25 %. The lowest and highest values of TS were achieved by the panels made of 75 % poplar and beech strands core layers, respectively (Fig. 6). Although no wax was used during panel manufacturing, overall dimensional stability of the panels are within an acceptable range compared to EN 300 for OSB type 2 with the exception of 100 % poplar strands and panel G (75 % poplar core strands). The results also showed thickness swelling values in panels made of beech strands core layers decreased with increasing density. Chen et al. (2010) investigated relations between major properties of OSB and panel density by carrying out a systematic and extensive pilot plant experiment. In their research, TS and water absorption linearly decreased with increasing panel density. They observed that higher density products absorb water slower and therefore reduce the rate of TS.

In addition, increased bonding in the core layer due to the positive influence of moisture during hot pressing (influence on IB) led to an increased resistance to water penetration and decreased the thickness swelling. The thickness swelling of beech and poplar strands with and without resin after 24 h was also examined. This test clearly showed that poplar strands absorbed more water compared to beech strands because of their lower density and higher permeability which could be another reason for TS reduction in panels made with higher amounts of beech strands.

4 Conclusion

The aim of this study was to determine the physical and mechanical properties of OSB made from different combinations of European beech and poplar strands, i.e. varied face/core ratios and two different densities. The results indicate that given the availability of these species in Europe, there is potential for a new raw materials market for OSB. All technical properties of these panels fulfilled the minimum requirements for OSB type 2 of EN 300 standard with the exception of panels made of 75 % poplar strands core layer. In general, panels with different face/core ratios show better properties compared to OSB manufactured from 100 % beech and poplar strands. Therefore, a mixture of these two low and high density hardwood species could possibly be used to introduce a new competitive product on the conventional OSB market and reduce the pressure to use softwoods, especially pine and spruce. As for the physical properties, thickness swelling and dimensional instability are important disadvantages of OSB. However, the result of this research showed that the thickness swelling values were acceptable compared to EN 300 standard which might be related: (1) to pMDI as water resistance glue and (2) also different panel designs and combinations to restrain this effect. In comparison, OSB made of beech strands core layers has higher MOR, MOE and IB values and also showed lower thickness swelling compared to poplar strands based core panels.

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The effect of fine strands in core layer on physical and mechanical properties of oriented strand boards (OSB) made of beech *(Fagus sylvatica)* and poplar *(Populus tremula)* (2014)

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ORIGINAL

The effect of fine strands in core layer on physical and mechanical properties of oriented strand boards (OSB) made of beech *(Fagus sylvatica)* and poplar *(Populus tremula)*

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Abstract This paper discusses the influence of three different content levels of fine strands in the core layers on the physical and mechanical properties of European beech and poplar oriented strand boards (OSB). The results show that increasing the fines content in the core layer from 10 to 50 %, based on total board weight has no significant effect on bending strength and modulus of elasticity (MOE). All panels exceeded the minimum requirement for bending strength and MOE set by EN standards. The highest modulus of rupture (MOR) and modulus of elasticity (MOE) was determined for panels solely made of poplar with different level of fines content. Increasing the amount of fines in the core layer raised the internal bond (IB). Panels made with 30 % fines in the core layer showed highest internal bond strength values. As the fines content increased from 10 to 50 %, thickness swelling decreased. Water absorption after 24 h showed the same declining trend as thickness swelling.

1 Introduction

Oriented strand board (OSB) is a major engineered wood based panel product widely used, for example, in wall and roof sheathing, flooring, packaging, and other structural applications. The USA and Canada account for 83 % of global OSB production. In Europe, OSB capacity increased by 50 % between 2003 and 2010 with a projected growth trend continuing until 2019 (Anonymous 2012). In addition, researchers are seeking for new product types and processing technologies in order to meet market demand. One key factor likely to affect the OSB market is the availability of reasonably priced raw materials. Softwoods, especially pine, are currently the main resource for OSB in Europe. These raw materials are also in demand for pulp and paper making and more recently, energy generation. One strategy to reduce this pressure on the softwood markets is to use more hardwoods for OSB. This complies with the current trend of replacing softwood forests by hardwood forests for ecological reasons. The increasing use of small-diameter softwoods and hardwoods in OSB production has potentially positive implications for sustainable OSB development and forest management (Han et al. 2007; Akrami et al. 2014). Manufacturing expense is another aspect of OSB production. Producers today are searching for cheaper raw materials to convert into value added products. After resin, wood represents the second greatest portion (31 %) of wood based panel production costs (Anonymous 2010). This study used small diameter European beech (*Fagus sylvatica*) and poplar (*Populus tremula)* as raw materials to produce OSB. Since beech and poplar are currently used mainly as fuel for heat and power generation, they might present a cheaper alternative to pine, which is the conventional raw material for most OSB mills, and which also is in high demand by other sectors. Another aspect of this study is the possibility of reducing production costs by using fine strands in the OSB core layers. Only a very few basic studies have been published on the effect of varying amounts of fine materials, their location in the OSB structure, and final board properties

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(Han et al. 2007; Mirski and Dziurka 2011). Theoretically, OSB face layers should consist mainly of thin and long strands of 8–15 cm in length and 0.3–0.7 mm in thickness. The generation of fine strands is inevitable during the flaking process. Depending on the log size and condition, 20–40 % of the total strand mass produced is fine material which is defined as strands that pass through a 3.18 mm square opening (Fakhri et al. 2006). The easiest way to use these small strands is for energy or particleboard production, but adding this material to the core layers of OSB could reduce production costs. Previous research showed that using flakes with a small amount of chips in the core layer (up to 30 %) does not significantly reduce the mechanical properties of the resulting OSB panels (Brinkmann 1979; Ehrentreich 1980; Barnes 2002; Jastrzab 2008). However, the fine strands change the internal mat structure and influence panel properties and the pressing process (Han et al. 2007). Using beech and poplar in OSB manufacturing is fairly new and will require further research into the different aspects of these new products (Akrami et al. 2014). The objectives of this research were (a) to introduce and determine the possibility of using European beech and poplar as raw materials for OSB in general and (b) to evaluate the effects of using fine strands in the core layer on the properties of OSB in particular.

2 Materials and methods

Poplar (*Populus tremula*) and beech (*Fagus sylvatica*) trees were harvested near Hamburg, Germany. The strands were generated by a knife ring flaker at Pallmann Company, Germany. The face strands had an average length of 125 mm, thickness of 0.7 mm, and width of 20–40 mm. The average dimensions of the fine strands that were added to the core layer were 30–50 mm in length, 10–30 mm in width and same thickness as normal strands. Figure 1 shows the normal and fine strands of poplar. The face strands were dried to 10 % m.c. Fine materials and strands for the core were dried to 5 % m.c based on oven dry weight. The normal strands and fine strands required for the core layer were blended separately with pMDI (polymeric diphenylmethane diisocyanate) resin with 5 % resin amount, and then mixed together before being manually formed (Fig. 2). The nominal thickness and density of boards were 16 mm and 650 kg/m^3. All the boards were manufactured with a Siempelkamp laboratory press at 180 °C and 240 s pressing time.

Fig. 1 Normal (*left*) and fine poplar strands (*right*)

Three different levels of fine materials based on the total board weight were used. The proportion of fines content in the core layer was 10, 30, and 50 % based on the total strand weight of the board, meaning 20, 60 and 100 % fines in the core (face/core: 50 %: 50 % by weight). Two replicates were used for each variant, and a total of 24 boards were manufactured. Prior to testing, the manufactured panels were conditioned at 65 % relative air humidity and 20 °C temperature for at least 2 weeks. Modulus of elasticity (MOE), modulus of rupture (MOR), internal bond (IB) strength, thickness swelling (TS24) and water absorption (WA24) after 24 h were determined based on the EN standards.

3 Results and discussion

The average values of modulus of rupture (MOR) and modulus of elasticity (MOE) for the major board axis (parallel to face strands), internal bond, thickness swelling and water absorption of all panels are presented in Table 1 and Figs. 3, 4, 5, and 6. The mean density was between 0.6 and 0.63 g/cm^3. Panels A with 10 % fine beech strands in the core layer showed the lowest density and, 0.637 g/cm^3 was the highest density for panels F and G made with 30 % fine poplar strands in the core layer. Except for thickness swelling which decreased in panels made with 10 and 30 % fine beech strands in the core layer, all other panels showed higher values of mechanical properties, IB compared to EN 300 standards. According to Figs. 3 and 4, the panels could reach the minimum requirement for OSB type 2. Between different treatments, panels made with pure poplar and 30 % fines in the core layer showed the highest MOR and MOE among all variations. The correlation between IB and TS indicates that panels with 50 % poplar in the core and normal beech strands in faces show the highest IB and lowest TS.

3.1 MOR and MOE

The results of MOR and MOE for different core layer compositions are illustrated in Figs. 3 and 4. In general, as

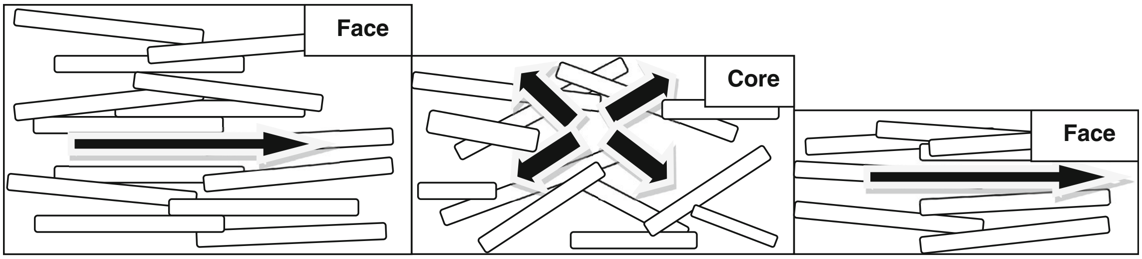

Fig. 2 Schematic OSB mat of this research

Table 1 Characterisation of OSB panels made from different fine strand amounts

Treatments	Panel type	Fine proportion in core layer (%)	Density (g/cm^3)	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	TS 24 h (%)	WA 24 h (%)
A	B	10 % fine	0.603	30,3	6,797	0.26	18	43
B	B+P+B		0.611	47	6,662	0.65	17	43
C	P+B+P		0.619	30.7	6,544	0.21	28	70
D	P		0.63	63.3	8,301	0.9	14	38
E	B	30 % fine	0.636	43	6,837	0.6	14	33
F	B+P+B		0.637	56.4	7523	0.99	12	36
G	P+B+P		0.622	39.2	8,464	0.46	21	47
H	P		0.637	71.2	9,882	0.93	14	38
I	B	50 % fine	0.631	39.3	7,523	0.52	13	31
J	B+P+B		0.613	68	7,338	0.53	10	45
K	P+B+P		0.631	43.5	8,751	0.43	20	33
L	P		0.633	65.4	8,843	0.72	11	35

B beech, *P* poplar, *MOR* modulus of rupture, *MOE* modulus of elasticity, *IB* internal bond, *TS* thickness swelling after 24 h

the fines content increased from 10 to 50 %, the MOR and MOE also increased, although there is no clear difference between panels made with 30 and 50 % fine strands. It is well known that bending strength and MOE are mostly influenced by the face layer of panels. Therefore, the fine materials did not show a major impact on the mechanical properties. Similar results were reported in a study by Mirski and Dziruka (2011). They investigated the utilization of chips from comminuted wood waste as a substitute for flakes in the oriented strand board core layer. Their results showed that the modification did not have a significant effect on bending strength or MOE determined in longitudinal axis of the OSB. In addition, Han et al. (2007) studied the influence of fines content and panel density on properties of mixed hardwood oriented strand boards and indicated that there was no consistent variation in the bending properties as fines content increased in the core layer. Table 1 indicates that all panels reached the minimum mechanical properties required for OSB type 2 according to EN 300 which are 20 and 3,500 N/mm^2 for MOR and MOE, respectively. Panel H reached the maximum MOR and MOE with 71.27 and 9,882 N/mm^2, respectively. The other remarkable point between panels was the MOR values of panels made of beech fines in the core layer. These groups of panels showed the minimum MOR values, however, it was higher than EN standard. During bending tests, shear failures occurred in the core layer throughout the length. This might be the reason for the lower MOR.

3.2 Ib

As the amount of fine strands in the core of OSB rose to 30 %, the IB in all panels increased. Except for panel H, the boards made with 30 % fines in the core layer showed at least a 50 % increase in IB compared to 10 % fines. It seems that the fine materials act as filler closing the voids between the normal strands, and in the presence of pMDI could improve the core layer and increase the properties. These results are in line with the previous research on fine materials for OSB manufacturing (Han et al. 2007). An increase in fines content from 30 to 50 % showed no significant influence. Panels made with 10 % beech fines in the core and normal poplar strands in the face showed the minimum IB value. During the internal bond test, the IB failure normally occurred in the core layer but in these samples the failure was observed in the interface between beech and poplar strands.

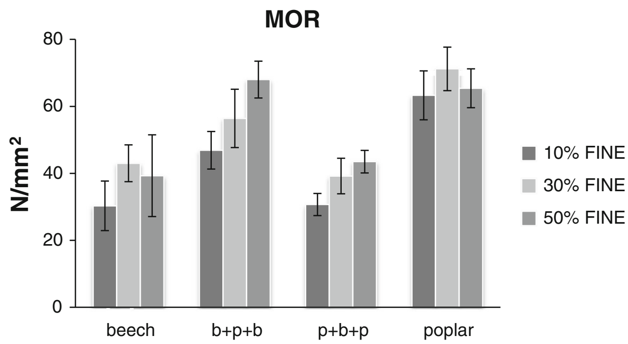

Fig. 3 Average MOR of fine core layers of 16 mm OSB. *b* beech, *p* poplar

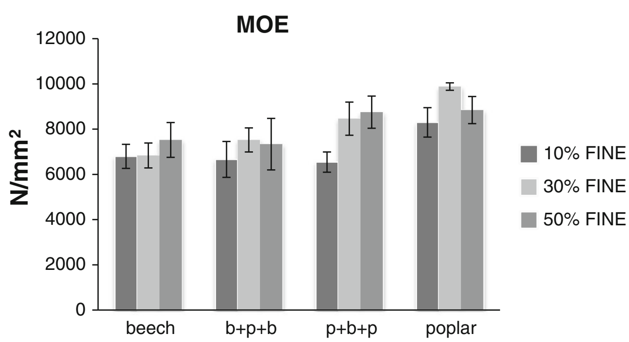

Fig. 4 Average MOE of fine core layers of 16 mm OSB. *b* beech, *p* poplar

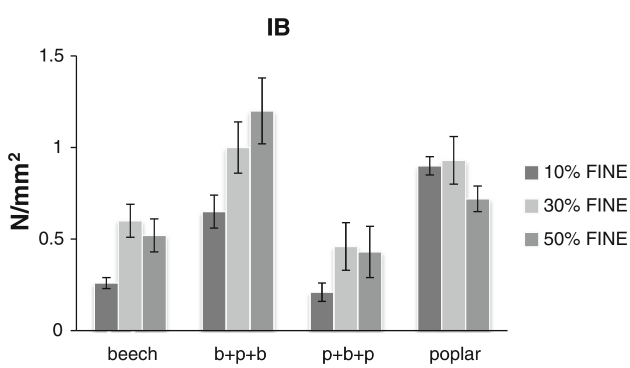

Fig. 5 Average IB of fine core layer of 16 mm OSB. *b* beech, *p* poplar

3.3 TS and WA after 24 h

The results of thickness swelling and water absorption after 24 h are shown in Figs. 6 and 7. In general, as the fines content increases, TS values decrease. Only panels made with beech fines (overall 10 and 30 % fines) in the core layer showed very high thickness swelling actually exceeding the EN 300 standard. Nevertheless, these types of panels can reach the acceptable EN 300 requirement

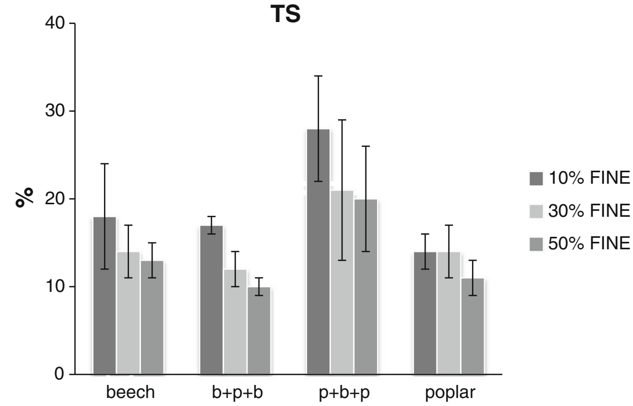

Fig. 6 Average thickness swelling of fine core layers of 16 mm OSB. *b* beech, *p* poplar

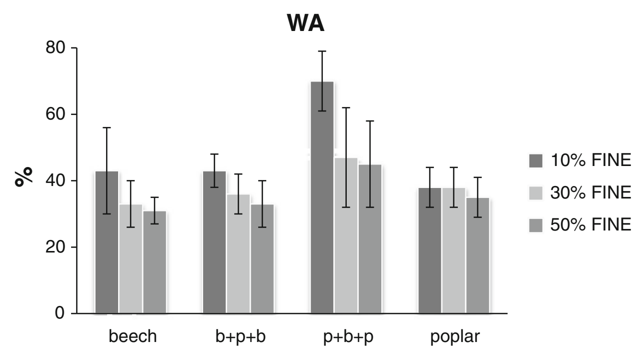

Fig. 7 Average water absorption of fine core layers of 16 mm OSB. *b* beech, *p* poplar

with 50 % fines in the core. Panels with 50 % beech fines or 50 % poplar fines in the core layer showed the lowest thickness swelling after 24 h with 13 and 11 %, respectively. The panels showed no significant variation in TS between 30 and 50 % fines in the core layer. Between these four panel groups, panels made with beech fines in the core and poplar strands in the face showed the maximum thickness swelling. Although an increase in fines from 10 to 50 % led the thickness swelling to decline from 28 to 20 %. Compared to panels made of poplar fines in the core layer, it was found that poplar could have a proper connection with pMDI and produce a high quality bondage that leads to increasing resistance to water absorption and higher IB. From Fig. 7 it can be seen that WA exhibited the same trend as TS. As the fine strands in the core layer increased from 10 to 50 %, the water absorption decreased. Han et al. (2007) investigated the influence of fines content and panel density on properties of mixed hardwood oriented strand board. In their research, the results indicated that the difference between linear expansion (LE) values was reduced with an increase in fines content of the boards.

3.4 Permeability

Previous research projects such as Haas et al. (1998); Hood (2004) and Dai and Yu (2004) indicate that the permeability of particleboard and OSB is affected by the size of the wood particle or strand length, width, thickness and also density. Fakhri et al. (2006) measured and modeled the effect of fines content on the transverse permeability of OSB panels and showed that the permeability of the core of commercial OSB is lower and much more variable than that of particleboard or MDF despite being of lower density. Therefore, using and also increasing the fine materials content in the core layer increases the permeability that results in a decrease of pressing time.

4 Conclusion

This study examined the use of fine core material and its effect on physical and mechanical properties of European beech and poplar OSB. Using beech and poplar as raw materials for the OSB market is rather new in Europe and little is known about the influence of fine materials in the core layer on OSB properties. Despite these limitations, the findings of this research show that using hardwoods like beech and poplar combined with board core layers consisting of up to 30 % of fine materials could introduce a different type of OSB to the market. The mechanical properties such as MOR and MOE and also internal bond reach the minimum requirement for OSB type 2 (EN 300). In addition, panels made with 100 % poplar and also panels made with 50 % fines in the core layer showed MOR and MOE at least two fold higher than required by EN 300 standards for OSB type 2. In the case of physical properties, an increase in fines content in the core layer of up to 50 % was followed by a decrease in thickness swelling after 24 h. The tests proved that fine materials not only could be introduced as an effective parameter to reduce OSB production costs, but it could also improve some practical OSB properties. The usage of fine materials in the core layer has no negative influence on bending strength and improves the internal bond strength. In addition, the fine materials have a positive effect on reducing the common problem of thickness swelling in OSB panels.

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Supplementing pine with European beech and poplar in Oriented Strand Boards (2014)

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ORIGINAL ARTICLE

Supplementing pine with European beech and poplar in oriented strand boards

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Abstract
The objective of the study was to compare the properties of oriented strand boards (OSBs) made from the following mixtures: European beech and poplar, beech and pine, poplar and pine and 100% pine (i.e. the conventional raw material for OSB in Europe). Panels with 50–50% of beech-poplar/beech-pine/poplar-pine at two density levels of 650 kg/m^3 and 720 kg/m^3 were made with 5% pMDI (poly methylene di-isocyanate) as binder at 180°C and 240s as press conditions. Results showed that panels comprising a mixture of European beech and poplar have higher mechanical properties compared to panels made with mixtures of pine-beech or pine-poplar. In addition, for all panels, when density is increased from 650 kg/m^3 to 720 kg/m^3, mechanical properties increased. Internal bond values for all designs were in the same range, especially at higher density (720 kg/m^3). The pure pine panels showed lower values between different designs. Thickness swelling, an important physical property of OSB, improved when face and core layers consisted of a mixture of beech and poplar strands.

Keywords: *European beech and poplar, OSB, pine, technical properties*

Introduction

The tremendous pressure currently placed on softwoods as the main source for engineered products (GLT, CLT, OSB) and sawn wood by the pulp and paper-making industry has spurred the search for alternative new raw material from suitable tree species. The main goals of this study was to find a substitute for pine strands in OSB and also to create new board types made from a mix of various European hardwood strands. Beech and poplar are two important and widespread wood species in Europe, available in most of the countries. Presently, the small-diameter logs of these tree species are mainly used by the energy sector. As such, it is worth considering the advantages of using these species for value-added products such as plywood, LVL and OSB. This concept would also support management strategies and promote cascade concepts (Knauf and Frühwald 2013).

This study was the third part of a project to examine opportunities to use European hardwoods as raw material for OSB manufacturing in Europe (Akrami *et al.* 2014a, 2014b). It is clear that, in the near future, supplying suitable raw material will be the main challenge for wood-based panels. In the case of OSB mills and markets, and in light of recent policies aimed at converting European softwood forests into hardwood forests, the use of alternative wood species in place of conventional raw material could present a valuable new strategy for producers.

The first part of this study examined European beech and poplar as possible raw material for OSB in an effort to reduce the pressure on softwood forests and create new opportunities for producers (Akrami *et al.* 2014a). The study showed that small-diameter beech (20–30 cm) and poplar (24–32 cm) trees are potentially valuable competitors to softwoods, especially to pine which is currently the main resource for OSB mills in Europe.

The second part of the study focused on the physical and mechanical properties of the fine strands in the core layer with different percentages and designs (Akrami *et al.* 2014b). The results not only showed that by using fine strands in core layers

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Figure 1. Hand-debarked beech logs.

the minimum values for OSB type 2 could be reached, but also showed that using fine strands could be key to reducing production costs.

As illustrated in the papers mentioned, almost all OSB producers use softwoods as raw material in their production lines. This study attempted to evaluate the possibility of using beech and poplar strands as a mixture as well as in a mixture including pine. The properties of boards produced in the lab were compared to the EN300 standard and also to pine panels that were made in the lab with the same conditions. Previous research studied the mixture of hardwoods with pine in small amount (less than 10%). Nevertheless, the use of hardwoods as the major part of raw material for OSB has not been studied. Only a few wood species have been utilized in large quantities for commercial OSB manufacture (Wang and Winistorfer 2000).

Materials and method

Small-diameter beech and poplar trees were harvested near Hamburg, Germany, and then manually debarked (Figure 1). The debarked logs were sent to PALLMAN Company in Zweibrücken to produce strands. The pine strands used in this study were obtained from Kronoply Company, Heiligengrabe. The pine strands collected after the dryer have 3–5% m.c. Since about 10% m.c was required for producing face layer, water was added to the strands in order to reach 10% m.c, and then the strands were packed in plastic bags for a uniform moisture distribution. The average pine strand dimensions were 150 mm, 0.7–0.8 mm, 20–40 mm for length, thickness, and width, respectively. Figure 2 shows three different strands which were used in this study. Using these strands, 16 mm OSBs were made with three layers with the core strands perpendicular to the surface layers and were hot pressed (180°C) at 650 kg/m^3 and 720 kg/m^3 for 240s. The forming was made manually into a 60 × 55 cm^2 wooden box. A total of 16 boards were produced using a lab press with a size of 80 × 60 cm^2 in the distance/thickness-controlled mode. OSB with 25:50:25% face/core/face (by weight) ratio made from mixtures of beech and poplar, beech and pine, poplar and pine (the mix percentage for each species was 50%), and also 100% pine strands were fabricated (Table I). As in previous study (Akrami *et al.* 2014a, 2014b), 5% poly methylene di-isocyanate (pMDI) was used. No wax or other additives were applied. After two weeks in a conditioning room at 65% RH and 20°C, the panels were tested for physical and mechanical properties. Information regarding the sample preparation and also the devices used for measuring modulus of elasticity (MOE), modulus of rupture (MOR) and internal bond (IB) strength can be found in previous papers (Akrami *et al.* 2014a, 2014b). MOE, MOR, IB strength and TS 24h (thickness swelling after 24 h) were determined based on the EN300 standard.

Results and discussion

As Table II shows, mechanical properties and IB increase with increasing density from 650 kg/m^3 to

Figure 2. Pine (left), poplar (middle) and beech (right) strands.

720 kg/m^3. Panels made from a mixture of beech and poplar (panels A and B) reached maximum MOR at two density levels, compared to other panels. Panel D (mixture of beech and pine) showed the maximum MOE with 8174 N/mm^2 at 720 kg/m^3 although the MOE value at 650 kg/m^3 is almost close to the panels made with a mixture of beech and poplar. The other noticeable point was the lower mechanical properties and also IB of pure pine panels among the different designs (except MOE at a board density of 720 kg/m^3). For instance, MOR of pine panels showed 53% lower value compared to mixed beech and poplar panels at 650 g/cm^3. Furthermore, in the case of physical properties, the mixture of beech and poplar strands showed the minimum TS 24h at both densities.

MOR and MOE values

According to Figures 3 and 4, the MOR and MOE values for the major board axis show that all panels reach the minimum requirements for OSB type 2 based on the EN300 standard. The results showed that the mixing of low and high density species (beech and poplar) could create panels with improved properties. It is well known that the strength properties highly depend on density. OSB panels made with beech and pine showed higher MOR and MOE when compared to panels made with a mixture of pine and poplar strands. This value might be related to higher density of beech strands compared to poplar. Panels made with pine reached the minimum values among all panels except MOE at 720 kg/m^3 although it is only 4% higher than panels B and F that show no significant difference.

Table I. Characteristics of the OSB.

Treatment	Panel type	Density (kg/m^3)
A	Beech + poplar (50/50% mix)	650
B	Beech + poplar (50/50% mix)	720
C	Beech + pine (50/50% mix)	650
D	Beech + pine (50/50% mix)	720
E	Poplar + pine (50/50% mix)	650
F	Poplar + pine (50/50% mix)	720
G	Pine	650
H	Pine	720

Internal bond

Figure 5 demonstrates that higher IB values were achieved at 720 kg/m^3. It means that with increasing density, IB is improved. These results agreed with values reported by Kajita (1987), Canadido *et al.* (1988), Sumardi *et al.* (2007) and Malanit *et al.* (2010) who determined the effect of board density and layer structure on the mechanical properties of bamboo-oriented strand board and revealed that IB was greatly affected by density and exhibited a similar trend in bending properties as function of density.

In addition to MOR and MOE, the pine panels showed lower IB compared to panels made from beech and poplar. Panels C and D made with a mixture of beech and pine strands reached higher IB value at both densities compared to other

Table II. Physical and mechanical properties of the lab-made OSB.

Panel	Density (g/cm^3)	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	TS 24h (%)
A	0.66 (0.3)	61.7 (6)	6839 (520)	0.87 (0.17)	13 (3)
B	0.73 (0.4)	69.3 (8.8)	7031 (685)	1 (0.16)	6.6 (1.3)
C	0.64 (0.1)	47.6 (9.8)	6951 (856)	0.91 (0.13)	23 (2)
D	0.73 (0.4)	65.2 (5.4)	8174 (416)	1.31 (0.16)	24 (2)
E	0.62 (0.4)	56.8 (3.1)	6769 (294)	0.61 (0.19)	16 (3)
F	0.7 (0.2)	58.5 (7.2)	7004 (223)	1.1 (0.11)	18 (1)
G	0.62 (0.3)	40.1 (4.8)	6043 (756)	0.79 (0.09)	22 (5)
H	0.71 (0.3)	55.8 (9)	7306 (614)	0.88 (0.07)	23 (2)

MOR, modulus of rupture; MOE, modulus of elasticity; IB, internal bond; TS 24h, thickness swelling after 24 h; standard deviation in parentheses.

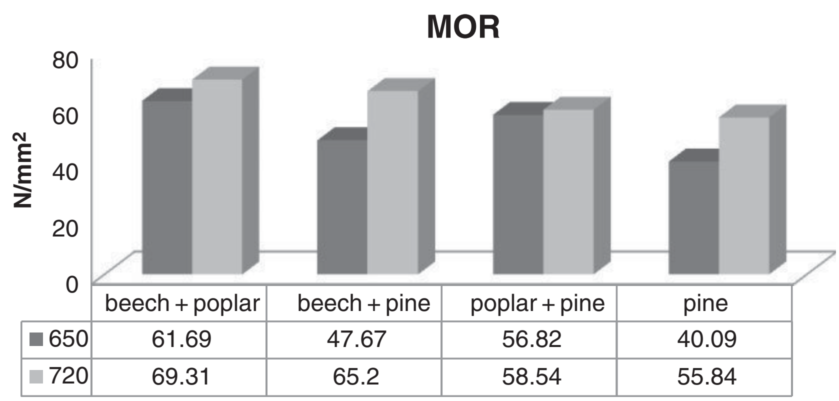


Figure 3. The effect of density and wood species on MOR (n = 6).

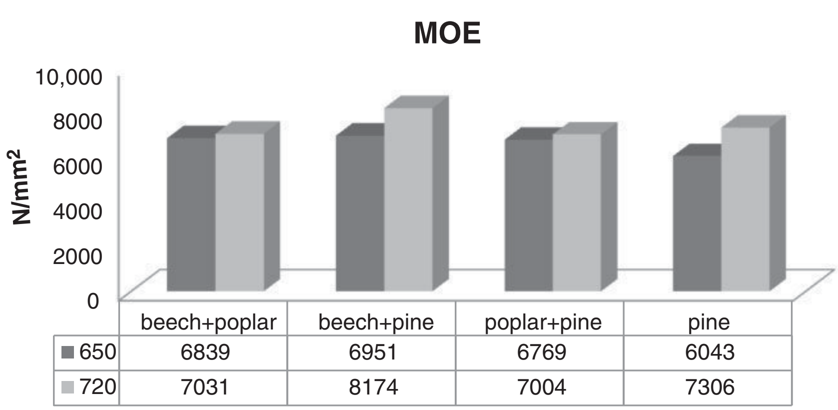
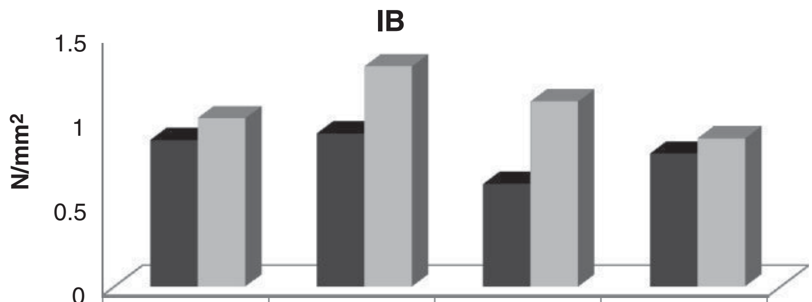


Figure 4. The effect of density and wood species on MOE (n = 6).

combinations that are at least 45% and 31% higher than pure pine and poplar and pine strands (at 720 kg/m^3), respectively. It is commonly accepted that density has an undeniable effect on mechanical properties and also on IB and it appears that the higher density of beech and pine species compared to poplar supports these conclusions. Therefore, the properties of OSB made of beech and pine are better compared to pure pine OSB or poplar-pine OSB.

TS 24h

Figure 6 illustrates the thickness swelling (TS) between different treatments. This figure shows



	beech + poplar	beech + pine	poplar + pine	pine
650	0.87	0.91	0.61	0.79
720	1	1.31	1.1	0.88

Figure 5. Average values of internal bond (IB) strength (n = 18).

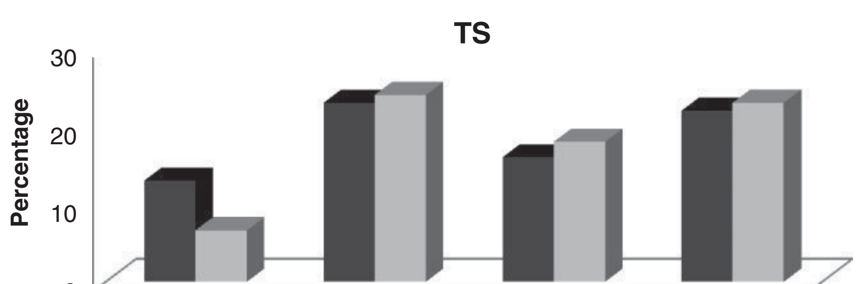
that pure pine panels and panels made with mixtures of beech and pine had almost the same TS, which is around 10% higher than maximum TS value per EN317 standard (20% for OSB panel type 2). Dimension instability, especially TS in the presence of water or moisture, is the main disadvantage of OSB (Young *et al.* 2009, Houts *et al.* 2006). In this study, OSBs were made in the lab without the addition of wax or other additives. The use of wax could be a solution for reaching the standard value. Xua *et al.* (2009) also used pMDI to produce particle board from bagasse. Their results showed water absorption and TS of panels improved after 24 h.

Interestingly, with regard to physical properties, panels made with a mixture of hardwood species recorded low TS values. Beech and poplar panels showed only one-third of EN300 standard's allowed value for TS at 720 kg/m^3. As discussed in a previous study (Akrami *et al.* 2014a), panels made from pure beech strands showed the same trend, and as density increased the TS value decreased.

Panels manufactured with higher compression levels during hot pressing show a higher tendency to spring back and swell to initial thickness before pressing. Because of high density of beech strands compared to poplar, these strands have received lower densification during the manufacturing of the panel in the hot press. On the other hand, the higher spring back of poplar strands might be masked by the beech strands. This could be the main reason for lower TS compared to other combinations. This trend was even observed at higher density (720 kg/m^3) because of higher amount of strands and lower compression to reach the thickness of the final panel.

Conclusions

This study is the third part of a scientific look at the potential for European beech and poplar to be used as raw material in OSB manufacturing. Although changing producer behavior is not easy, these studies nevertheless aim to encourage the industry to use these suitable/new materials as an alternative to pine in OSB production. The study at hand focuses on experimental OSB made with beech and poplar strands and compares OSB with pine strands, Europe's conventional OSB material. The results demonstrate that using beech and poplar as a mixture could achieve the same properties as boards



	beech + poplar	beech + pine	poplar + pine	pine
650	13	23	16	22
720	6.6	24	18	23

Figure 6. Average values of thickness swelling (TS) (n = 18).

made from pine as well as the minimum properties required for OSB type 2. In addition, the mechanical properties of boards made from a mixture of pine and beech or pine and poplar could offer improved properties compared to pure pine-based panels. Therefore, substituting current raw material with hardwood species presents valid possibility for producers to consider. This could reduce concerns about raw material supplies while also alleviating the pressure on softwood forests and the softwood markets in Europe. With regard to physical properties, mixing beech and poplar strands shows the potential for reducing TS 24h, representing an important achievement for OSB. In addition to the technical properties, using low quality and small-diameter beech and poplar trees could be a key factor in lowering OSB production costs.

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Palms - An Alternative Raw Material for Structural Application

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Abstract

The three main species of palms are oil palm, coconut palm and date palm. Their total plantation area is close to 30 million ha. Oil palm is the most important one with a sustainable production of more than 150 million m³ of trunks per year. The main goal of this research was to produce and test strand board made of oil palm trunk (OPT) as well as in mixture with poplar and coconut palm wood. The produced boards were 13 mm thick, 550 kg/m^3 in density, press time 320s, using 5% pMDI. 100% OP strands or a mix of OP with poplar or light Coconut wood. The results showed that panels with 100% oil palm had higher properties compared with EN300 standard but panels made with poplar as face and oil palm as core had the highest MOR and MOE. A mixture of coconut and oil palm showed the best internal bond (IB). No significant IB difference observed between panels made with a mixture of poplar/oil palm and poplar as face/oil palm as core. Highest and lowest thickness swelling was found with 100% oil palm and a mixture of coconut and oil palm, respectively. The paper analyses the structural and mechanical properties of oil palm wood in relation to the strand board properties and gives a brief recommendation of further studies and for commercial production of OSB/CSL.

Keywords: Oil palm, poplar, coconut palm, oriented strand board, physical and mechanical properties, area of wood utilization

Introduction

Wood based composites are widely used for various applications in the building and furniture sector. The demand for wood composites is growing continuously. One aspect of present and future research is focused on new product design and uses for load bearing and non-load bearing constructions in both residential and commercial buildings. Oriented Strand Board (OSB), Oriented Strand Lumber (OSL) and Parallam are some examples for load bearing composites. The shortage of current raw material and increasing costs requires new raw materials for these products. Due to this challenge, finding suitable wood and/or non-wood raw material is one of the serious challenges for the future. One strategy is the use of non-commercial fiber materials as an alternative for OSB, OSL, and Glued Laminated Timber (GLT) or Cross Laminated Timber (CLT). The most available materials of this type are bamboo and palms. Also a combined use of these materials with traditional timbers is a promising option. Malanit (2009) has already shown the potential of bamboo for OSB with excellent product properties.

Palms have similar physical, mechanical and chemical properties like wood (Killmann & Lim 1985). Palms are found naturally or planted on large areas throughout the world but mainly in Asia and West Africa. Generally, palms are cultivated to provide oil and fats (oil and coconut palm) or fruits (date palm). When the fruit production declines the old palms are replaced and the trunks of the palms (OPT) have a potential for product use or energy purposes. The highest potential has oil palm and coconut palm which are planted on 20 million ha and 5 million ha, respectively. The single plots planted with coconut are small which creates huge logistic and supply problems. Oil palm is often planted on large and very large sites. The life time of an oil palm tree is 25 years before replanting and the available volume per ha at the time of replanting is 150-200 m^3. Considering the existing 20 million ha (mainly in SEA) 800.000 ha have to be replanted every year which give a theoretical volume of 120-160 million m^3 OPT per year. At least 75% are located in Indonesia, Malaysia and Thailand where the harvest of traditional timber for the industry from natural forest will fall below 50 million m^3 together in the three countries. OPT is a lignocellulosic material which is sustainable available, and cheap, has no harvesting or trade restrictions and is therefore a raw material with a good potential to reduce the pressure on softwood/hardwood forests (Sulaiman *et al*. 2009).

Objectives

The objectives of a recently performed research project were a) to produce and test oil palm based OSB with 100% strands from Oil Palm Trunks (OPT) and b) to test a mixture of OPT strands with strands from low density coconut wood and poplar as low density hardwood.

Material and methods

Strand preparation

Small diameter poplar trees were harvested near Reinbek, Germany. After debarking manually, the logs were converted into strands at PALLMANN (Zweibrücken). A knife ring flaker produced poplar strands in dimension of 12.5 cm in length, 0.7 mm in thickness and 20-40 mm in width. The wet strands were collected in plastic bags and transported to Hamburg and immediately dried in a kiln.

The oil palm (OP) material used in the tests came from Southern Malaysia Peninsular and was originally used as core layer in 30 mm thick block board. From the block boards which were tested in Hamburg, the core material was removed and used to produce strands. In order to increase the moisture content before the stranding process the boards were put in water for half an hour. The strands were produced by sawing using a circular saw (Fig.1). Due to low density of the used oil palm wood (0.30 g/cm^3), it was not possible to produce thinner strands than 1.0 mm. This is due to the very low density and therefore low splitting properties of the parenchyma and the high cutting forces during circular sawing. The strands produced had overall dimensions of 1 mm thick, 20 mm width and 125 mm length (same as poplar).

Figure 1. Producing strands with circular saw in the lab

Coconut timber *(Cocos nucifera)* was obtained from a plantation in Northern Sulawesi, Indonesia. The density ranged from high (600-900 kg/m^3) to low density (200-400 kg/m^3). For the OSB the lower density timber was selected (300-450 kg/m3) to be comparable to the Oil Palm material.

Figure 2. Strands from poplar (left), coconut palm (middle), and oil palm (right)

Panel manufacturing

Four different types of panels were produced for this study. A) pure (100%) oil palm OSB, B) mixture of oil palm and poplar with 50/50 % ratio, C) poplar as face and oil palm as core layer, and D) mixture of oil palm and poplar with 50/50 % ratio. Table 1 shows the material combinations and design of OSB panels.

Table 1: Characterization of OSB panel

Samples	Panel type	Ratio by mass (%)	Target Density (kg/m³)	Target Board Thickness (mm)
A	oil palm	100	550	13
B	mix of poplar/oil palm	50/50		
C	poplar /oil palm/ poplar	20/60/20		
D	mix of coconut/oil palm	50/50		

The moisture content of the strands after storage and conditioning was 10% for face and 5% for core strands. These strands were separately blended with 5% polymethylene diisocyanate (pMDI) as adhesive in a drum blender. No wax or other additives were applied. A wooden frame (40*40 cm^2) was applied to form the mat. For each panel type A-D two panels were produced. The forming of the tree layer panel (with the core running perpendicular to the faces) was done by hand. This certainly is not comparable to an industrial process. Pressing parameters were 180°C, press time 320s, final thickness 13 mm and target density after pressing 550 kg/m^3. Before testing, all the test specimens were conditioned at 65% RH and 20°C for 1 week. Modulus of elasticity (MOE), modulus of rupture (MOR), internal bond (IB), thickness swelling after 24h (TS24h), and vertical density profile (VDP) of the boards were measured and compared with EN300 standards. Samples for testing MOR and MOE (3 samples), VDP (1), IB (6) and TS (6) were cut from each panel to determine properties. For the measurement of MOR and MOE according to EN 310, a Zwick/Roell Z050 universal test device was used. The internal bond strength test was performed with a universal testing machine as well (Losenhausenwerk). Samples for thickness swell were prepared and tested according to EN 317. Average thickness was measured in the center of each sample. The samples were submerged in water at 20°C for 24h. Then the specimens were dripped and wiped clean of any surface water. The thickness of specimens was measured with digital caliper of 0.01 mm precision. Determination of the cross sectional density profile was conducted using gamma-ray densitometry.

Results

The average values of modulus of rupture (MOR) and modulus of elasticity (MOE) for the main board axis (parallel to face strands), internal bond, and thickness swelling of all panels are presented in Table 2 and Figures 3 through 7. The average oven dried density for all panels after pressing was around 0.60 g/cm^3.

Table 2: Average physical and mechanical properties of OSB

Panel	Density (g/cm^3)	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	TS (%)
A	0.61 (0.02)	23.4 (5.1)	3846 (555)	0.57 (0.03)	30 (4)
B	0.62 (0.04)	47.3 (7.0)	6071 (737)	0.64 (0.06)	17 (2)
C	0.61 (0.03)	51.2 (6.8)	6767 (829)	0.65 (0.05)	14 (2)
D	0.63 (0.03)	30.5 (7.0)	4565 (579)	0.8 (0.08)	13 (3)

MOR: modulus of rupture MOE: modulus of elasticity, IB: internal bond,
TS: thickness swelling after 24h, Standard deviation in parentheses

Vertical density profile (VDP)

Figure 3 shows the average vertical density (density along board thickness) among different panels. As shown in figure 3, panels made with a mixture of coconut and oil palm strands showed the highest density compared with panels made with a mixture of poplar/oil palm or pure oil palm. In addition, panels made with 100% oil palm and oil palm in core layer showed the same vertical density profile. In general, high density face and low density core layer are the main characteristic of oriented strand board. The result with all board types is a mean density between 0.61 and 0.63 g/cm^3 regardless of the combination of the three material types. This leads to the assumption that the densification of the strands of poplar (350 kg/m^3), coconut palm (400 kg/m^3), and oil palm (300 kg/m^3), after board pressing results at the same density of some 600-650 kg/m^3. This means that densification ratio for poplar strands is 1.7, for coconut strands 1.5 and for oil palm strands 2.0.

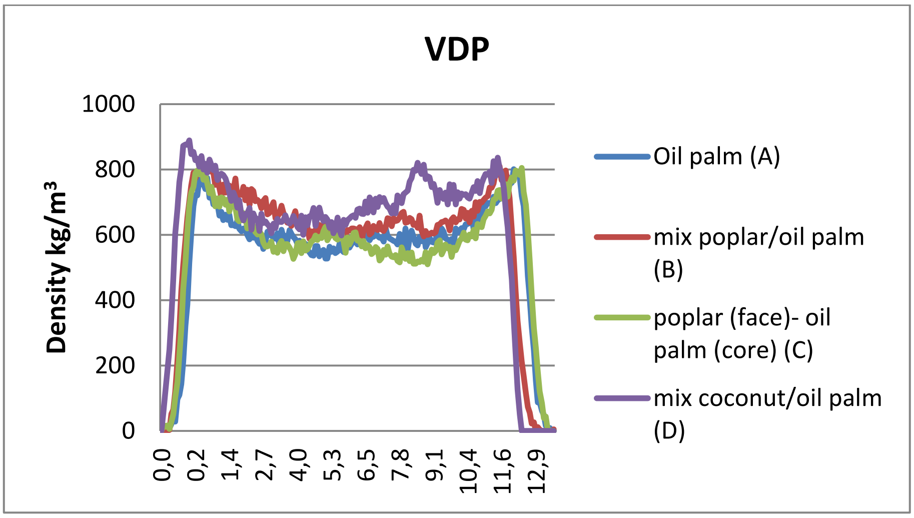
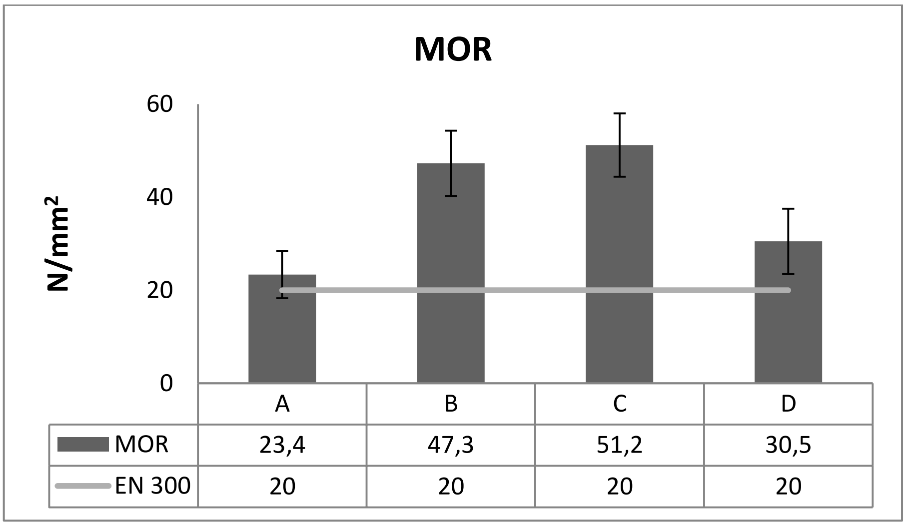


Figure 3. Vertical density distribution

MOR & MOE

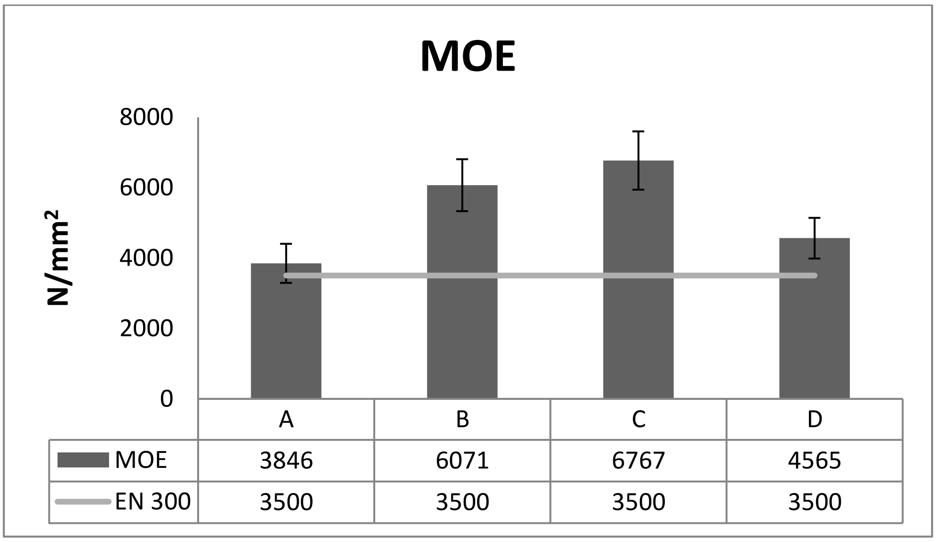
The results of MOR and MOE for the different panels are illustrated in Figure 4 and 5. The same trend was observed for MOR and MOE among the panels. Panels made with poplar strands in face layer showed 51.2 and 6767 N/mm^2 as MOR and MOE, respectively. It is well known, bending strength and MOE of wood based composites relates to face layer properties and thickness. Because of higher MOR/MOE properties of poplar compared to coconut and oil palm considering the same density after compressing of the boards, the panels with poplar in face either 100% (C) or 50% (B) have the better bending properties.



A: Pure oil palm, B: mixture of poplar and oil palm,

C: poplar (face) + oil palm (core), D: mixture of coconut and oil palm

Fig 4. Average MOR of 13 mm OSB



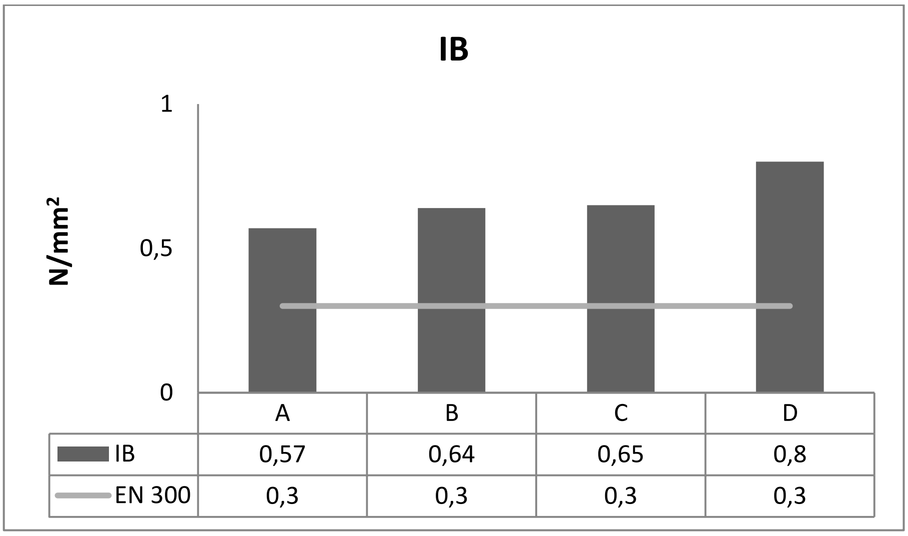
A: Pure oil palm, B: mixture of poplar and oil palm,

C: poplar (face) + oil palm (core), D: mixture of coconut and oil palm

Fig 5. Average MOE of 13 mm OSB

Internal bond (IB)

The results showed that the internal bond values of the test samples vary between 0.57 and 0.8 N/mm^2. Mean IB of all boards was considerably higher than the minimum requirement for OSB type 2 which is 0.3 N/mm^2 (EN300). The results show that panels made of type A (100% oil palm) and type B (poplar as face and OP in core) has no big influence on the IB. It means that the glue line properties are sufficient and shows the good bonding between oil palm strands and pMDI. Panels made with a mixture of 50-50% coconut and oil palm showed the highest IB among the different combinations. It may be related to the role of oil palm as filler in core layer because of lower original density compared with coconut and most likely higher flexibility across grain.



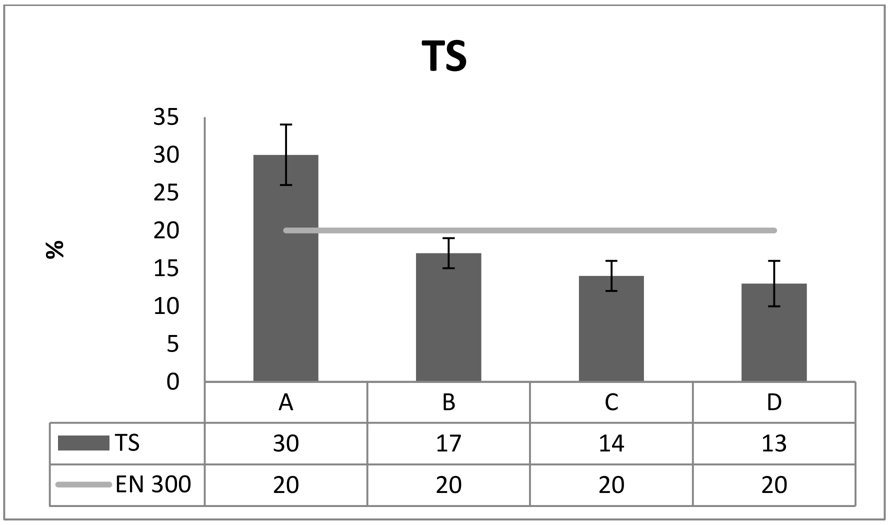
A: Pure oil palm, B: mixture of poplar and oil palm,

C: poplar (face) + oil palm (core), D: mixture of coconut and oil palm

Fig 6. Average IB of 13 mm OSB

Thickness swell 24h

The lowest and highest values of TS were observed with the panels consisting of 100% oil palm and panels made with a mixture of coconut/ oil palm, respectively (Fig. 7). EN 319 defines the maximum TS level for OSB type 2 to 20%. Even having used pMDI the test results show that thickness swelling remains as big disadvantage. One strategy to reduce the thickness swelling could be use of wax or paraffin. This problem could be also solved by treating strands with water repellent before panel manufacturing (Yalinkilic *et al*. 1998) or heat treatment in order to reduce water uptake. As shown in Fig.7 oil palm panels had the lowest TS which might be related to different structure of the wood (vascular bundles and parenchyma) especially the influence of high densification rate on the parenchyma. Physical properties of oil palm trunks differ significantly, as vascular bundles are dense and fibrous, while parenchyma tissue is sparse and spongy (Lim& Khoon 1986, Lim & Fujii 1997, Baker *et al*. 2008). In panels C and D, lower thickness swelling might be related to lower thickness swelling of poplar and coconut strands. Oil palm has more pores compared to poplar and coconut that would be more void spaces for water uptake and storage.



A: Pure oil palm, B: mixture of poplar and oil palm,

C: poplar (face) + oil palm (core), D: mixture of coconut and oil palm

Fig 7. Average TS of 13 mm OSB

Discussion

Akrami *et al*. 2014 used beech and poplar as two potentially important wood species for oriented strand boards in Europe. The panels produced had 16 mm thickness at 650 and 720 kg/m^3 with 180° C and 240s, using 5% pMDI. A comparison between this current research and beech and poplar based OSB showed: Oil palm boards showing the same MOR as panels made with 100% poplar at 650 kg/m^3 but MOE of OPboards are about 25% lower. The IB was comparable to panels made with 50% poplar as core and 50% beech as faces (0.53 N/mm^2). The maximum TS were found 25% for panels made with 75% poplar as core/ 25% beech as face layer , and also pure poplar panels at 720 kg/m^3 (23%) but for OPboard is around 30% (only 610 kg/m^3) . The mixture of coconut and oil palm has the same TS like panels with 50% beech in core and 50% poplar in face at 650 kg/m^3.

The materials from oil palm (OP) and coconut palm (CP) were from the very light weight part of trunks. All palms show a very distinct density variation within the trunk (Shaari *et al*. 1991, Frühwald *et al*. 1992)ranging between 0.2 to 0.8 g/cm^3 dry density (OP) and 0.3 to 1.1 g/cm^3 (CP). The idea of this research was to use the lower density parts of the trunks as the high density parts could achieve revenues as solid wood products in the market. If processing, logistics, and costs are taken into account, it is recommended to use the whole OP-trunk or the upper 2/3 of the trunk (with varying densities) for OSB.

Conclusions

In this research the typical properties of strand board from 100% oil palm wood and also in a mixture with poplar and coconut wood were determined. The results showed that the oil palm strands have a good potential to be used for OSB and could be a new alternative bio-based material for wood strands. Although the density of oil palm and the anatomical structure are two limitations of this material for some applications like building sector the results of this research show that a mixture of oil palm material for core layer with other tree species (i.e Acacia mangium or Rubber wood) as face layer could increase the properties of structural oriented strand board or continuous strand board (CSL).

ACKNOWLEDGEMENT

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14th International Panel Products Symposium, Llandudno, Wales, U.K. 2013

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EUROPEAN HARDWOODS FOR REDUCING THE DEPENDENCE ON PINE FOR ORIENTED STRANDS BOARD

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SUMMARY

Physical and mechanical properties of OSB made with mixture of beech and poplar strands were compared to boards made purely of beech, poplar and pine at 650 and 720 kg/m^3. The mixed beech and poplar strand boards showed better properties in bending strength and IB compared to pure panels. In addition, MOR and MOE were found to reach values two times higher than the levels as specified in EN300 the standard at a density of 720 kg/m^3. Thickness Swelling (TS) after 24hours for panels of mixed beech and poplar strands were 13%, which is around 35% less than EN300 allows.
Keywords: OSB, European beech and poplar strands, physical and mechanical properties

INTRODUCTION

An increasing trend for wooden buildings in both commercial and residential sectors has led to a growing demand for wood based panels in structural applications, especially oriented strand boards (OSB). In the USA and Canada OSB is widely used by the construction sector, (Young et al., 2009; Barbuta et al., 2011) Generally, OSB panels consist of strands or flakes with rectangular shape combined with thermo-setting resins like PF or pMDI (high water resistance resin). . Due to increasing demand for OSB in Europe in recent years, scientists and manufactures have been tried to improve and modify the current production to supply this product. One important issue that OSB market has to deal with is to get sufficient and suitable raw materials. Attempts have been made to substitute common wood species for OSB with other materials like bamboo or fast growing species (Okino et al., 2004; Sumardi et al., 2007; Febrianto et al., 2010). However, almost all OSB production in Europe is based on softwood species such as pine and spruce. Increasing pressures on safe guarding softwood forests and the need to reduce the impact of volatile organic compounds (VOC) emissions on indoor air quality (high VOCs from pine) are having a limiting effect on the use of OSB in Europe. This study looked at two important alternative EU hardwood species, beech and poplar, that are available in most of European countries as a raw material for OSB production.

MATERIALS AND METHODS

Strand preparation

In this research pine (*Pinus sylvestris*), beech (*Fagus sylvatica*) and poplar (*Populus tremula*) strands were chosen. Small diameter beech and poplar trees were harvested locally. After debarking the logs by hand, a lab knife ring flaker produced beech and poplar strands in dimension of 12.5 cm in length, 0.7 mm in thickness and 20-40 mm in width, at the Pallmann factory in Zweibrücken. The wet strands were collected in plastic bags and transported to Hamburg. To reduce the risk of fungal attack and decay, the strands were immediately dried in a kiln.

Pine strands were obtained from Kronoply in Heiligengrabe, gathered directly after drying. These strands had a moisture content of 3 to 5%.

Panel manufacturing

The moisture content of the strands after storage and conditioning was 10 and 5% for face and core strands, respectively. These strands were separately blended with 5% Polymethylene Di-Isocyanate (pMDI) resin in a drum blender. A 25:50:25% face/core/face ratio was made from mixtures of beech and poplar and control panels were made using only beech, poplar or pine (Table 1). OSB 16 mm panels were made with densities of 650 and 720 kg/m^3. No wax or other additives were applied. A total of 16 different boards of mixed and pure strands were manufactured at 180°C using a press time of 240s (using two replicates per treatment). Before testing, all the test samples were conditioned at 65% RH and 20°C for 3 weeks.

Modulus of elasticity (MOE), modulus of rupture (MOR), internal bond (IB) and thickness swelling after 24h (TS24h) of these boards were measured and compared to EN300 standards. Table 1 shows different design and combination of OSB.

Table 1: Characterization of OSB panel

Panel code	Panel type	Ratio	Density
A	Pure beech	100%	650
B	Pure beech	100%	720
C	Pure poplar	100%	650
D	Pure poplar	100%	720
E	mix beech and poplar	25:50:25%	650
F	mix beech and poplar	25:50:25%	720
G	pure pine	100%	650
H	pure pine	100%	720

RESULTS AND DISCUSSION

The average values of all physical and mechanical properties of the panels are illustrated in Table 2. The first point to note is the improvement in mechanical properties with increasing panel density from 650 to 720 kg/m^3. These results are similar to previous research (Vital et al., 1974; Nishimura et al., 2001). The maximum MOR and MOE were achieved by panels made with mixtures of beech and poplar. The second important point was lower properties values of pure pine panels compared to the mixture of beech and poplar panels.

Bending strength

As Table 2 shows, MOR and MOE increase with increasing density. In comparison between panels made with a mixture of beech and poplar with pure panels, these panels showed better properties. Low density species like poplar have low stiffness and strength. Therefore a combined high (beech) and low (poplar) density species could be one way to improve the panel properties. In addition, it is well known that bending properties are highly related to the face layer properties and that the core layer has a proportionally lower effect. This might be the reason for the lower MOR and MOE of the pure pine panels which have a lower density compared to beech. For modulus of elasticity (MOE), the same trend as for MOR was observed. The highest MOE was achieved using pure pine at 710Kg/m^3 but this was not significantly different to that achieved with the mixture of pine and poplar furnishes.

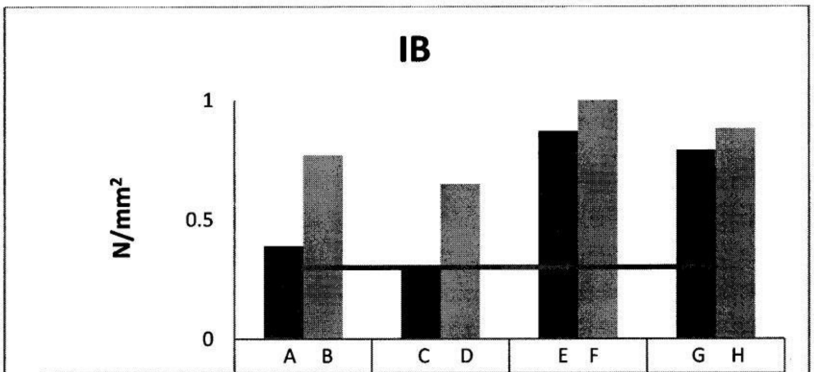
Table 2: Average physical and mechanical properties of OSB

Panel	Density (g/cm^3)	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	TS (%)
A (Beech)	0.63(0.02)	35.8(4.3)	6317(200)	0.39(0.13)	16(3)
B (Beech)	0.73(0.01)	52.5(5.4)	6888(331)	0.77(0.08)	12(2)
C (Poplar)	0.66(0.03)	23.7(2.8)	4980(212)	0.30(0.1)	19(3)
D(Poplar)	0.71(0.04)	42.5(6.5)	5443(696)	0.65(0.13)	23(3)
E (Poplar & Beech)	0.66(0.3)	61.7(6)	6839(520)	0.87(0.17)	13(3)
F (Poplar & Beech)	0.74(0.4)	69.3(8.8)	7031(685)	1(0.16)	6.6(1.3)
G (Pine)	0.62(0.3)	40.1(4.8)	6043(756)	0.79(0.09)	22(5)
H (Pine)	0.71(0.3)	55.8(9)	7306(614)	0.88(0.07)	23(2)

Notes: MOR: modulus of rupture MOE: modulus of elasticity, IB: internal bond, TS: thickness Swelling after 24h, Standard deviation in parentheses

Internal bond

PMDI resin is one of the thermosetting resins that could be used for OSB in both the surface or core layers. In Figure 1 it can be seen that increasing density had a positive effect on internal bond of all panel types.



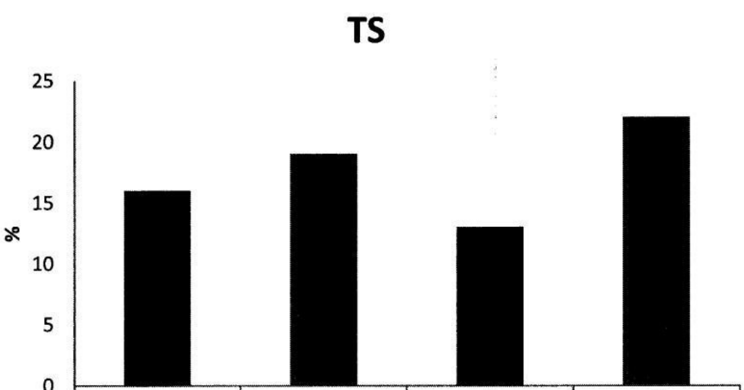
	A B	C D	E F	G H
650	0.39	0.3	0.87	0.79
720	0.77	0.65	1	0.88
EN STANDARD	0.3	0.3	0.3	0.3

Figure 1: Average IB of the panels

All panels met the minimum requirement for OSB type 2 except the panel made with pure poplar strands at 720 kg/m^3. Panels E and F (mixture of beech and poplar strands) showed the highest IB values. During the hot pressing process the presence of moisture might be the reason as this could increase the plasticization of the beech strands, which in turn increases the contact to low density poplar strands. Another influence may be that the poplar strands, due to lower density, act as a "filler" between the beech strands and consequently filled the holes and increase the IB strength.

Thickness swelling after 24h

The poor thickness swelling (TS) properties of OSB in humid and wet areas is a limiting factor in many applications. To improve and minimize the TS waxes are added to the wood furnish before or during blending (Zhang et al., 2007). The wax acts as a water repellant and slows down moisture ingress (Maloney, 1993). In this series of experiments no wax was added to any of the strands and panels made from beech and poplar had the lowest 24hrs TS. Panels with pure beech had a lower TS value than that specified in the standards for OSB Type 2.



	A	C	E	G
■ 650	16	19	13	22

Figure 2: Average TS of the panels

The density of beech is lower than poplar wood. It is suggested that during compression in the hot press poplar strand endured higher pressures that in turn led to higher internal gas pressures within the core of the panel. In some cases the gas pressure generated in the panel may be greater than the bonds between the pure poplar or pine panels. This gas pressure might be more powerful than the bonding between strands and this could result in cracks that then provide suitable pathways for water to penetrate. The higher density strands of the beech panels are more resilient and the glue line is more stable between the strands and the resin. Additionally, the strands of low density species have a tendency to return back to the initial thickness before pressing. It seems that in case of panels made from a mixture of beech and poplar, the beech strands are limiting this negative effect and reducing the amount of spring back.

CONCLUSIONS

The results indicated that using European beech and poplar as raw materials for the production of OSB, the minimum requirements of the EN300 standard for OSB Type 2 could be met. The MOR and MOE properties of panels made of mixed beech and poplar strands had values twice that needed for EN300 at a density of 720 kg/m³.

The important limiting property of oriented strand boards is thickness swelling. The results of this research indicated that mixing beech and poplar strands as raw material had a good potential to reduce the thickness swelling after 24h, even without the use of wax and other additives. The TS after 24hrs for these panels was 13%, i.e. around 35 % less than the level allowed by the EN300 standard.

These results showed that it is feasible to use European beech and poplar as raw materials for OSB manufacture. Test data indicates it is possible to produce OSB Type 2 with the same or even better properties compared to pure pine. This offers opportunities for the industry in Europe to use alternative wood species that could assist in meeting the future demands of the construction industry.

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European Beech and Poplar for Oriented Strand Board Manufacturing

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Background

Oriented strand boards (OSB) are one of the important engineered wood based panels for various applications such as wall and roof sheathing, flooring, packaging, and other structural applications. With 5.3 m3/year in 2012 (WBPI 2013), OSB holds 7% among the wood composites in Europe. An increasing demand for housing and other construction material will lead to higher volumes.

One of the key issues today is the raw material. Almost all OSB in Europe is produced with softwood species which face an increasing problem in volumes and prices. But suitable raw material and availability are important factors for the OSB sector. In particular, pine is the most desirable species for OSB manufacturing in Europe. The production of wood based panels and pulp and paper mainly depends on softwoods. Therefore, shortage and price of pine will be two affective factors in some years and it would be an expensive commercial raw material for OSB industries. In addition due to the amount of volatile extractives, volatile organic compound (VOC) is a major concern of products deriving from softwoods, especially Pine.

On the other hand two important wood species which are available in large quantities in whole Europe are beech and poplar. Germany for example presently has 15% of the forest area covered with beech with increasing area and volume (Janssen, 2008). Small diameter logs of beech are abundant available but used for producing energy. It easily could be converted to value-added panel products. In Europe poplar plantations cover a total area of 950.000 hectares (Coaloa & Nervo 2011)

In order to investigate the suitability of beech and poplar for OSB a research project was designed to evaluate the possibility of using beech and poplar as raw materials for OSB and develop OSB from these species with high mechanical properties for the building sector.

Materials and methods

In this research after debarking the logs and preparing strands by laboratory knife ring flaker, the beech and poplar strands were prepared for 100% beech, 100% poplar and 50-50% face/core ratio (50%beech in face layers - 50% poplar in core layer and vice versa), with target panel densities of 650 and 720 kg/m3 and using polymeric methylene diphenyl di-isocyanate (pMDI) as the adhesive. The hand-formed resinated mats (600*550*16 mm) were pressed using a Siempelkamp press in the lab under 180°C and 240s. All test samples were conditioned at 65%

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RH and 20°C then physical and mechanical properties such as modulus of rupture and modulus of elasticity, internal bond strength, and thickness swelling after 24h were measured and compared to European Standard (EN300).

Results

The results indicated that pure beech and poplar panels as well as different combinations could be a powerful alternative for pine based OSB. Table 1 illustrates that all mechanical properties and the internal bond meet the minimum requirement of OSB type2 in EN300.

Table1: Average physical and mechanical properties of OSB

Panel type	Ratio	Density (kg/m^3)	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	TS (%)
Pure beech	100%	650	35,88	6317	0.4	16
Pure beech	100%	720	52,53	6888	0.77	12
Pure poplar	100%	650	23,77	4980	0.3	19
Pure poplar	100%	720	42,49	5443	0.65	23
Beech+Poplar+Beech	25:50:25%	650	39,5	4956	0.53	12
Beech+Poplar+Beech	25:50:25%	720	49,39	5843	0.56	20
Poplar+Beech+Poplar	25:50:25%	650	47,8	5310	0.63	13
Poplar+Beech+Poplar	25:50:25%	720	49,95	6050	0.7	9
OSB/2 (EN300 Standard) Major axis	Board Thickness Range,(mm) >10 and < 18		20	3500	0.3	20

MOR: Modulus of Rupture, MOE: Modulus of Elasticity, IB: Internal Bond, TS: Thickness Swelling after 24h With increasing density all mechanical properties and also internal bond increased. Higher MOR and MOE values of panels made of 100% beech compared to pure poplar related to higher density of beech strands in face layer. In addition, panels made of pure beech showed higher IB compared to different treatments. It seems that higher densification of beech strands in presence of moisture and temperature during hot pressing lead to better bondage between strand-resin and strand-strand interfaces. In case of physical properties, all TS values were lower than required by EN standard except of pure poplar at 720 kg/m3.

The results of this work will open new doors for the use of hardwoods for OSB especially European beech and poplar to enhance to wood supply and create a new OSB type.

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European Beech and European Poplar – Densification and Design of OSB-Boards

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Abstract

In this research the behavior and characteristics of European beech and poplar and the influence of additives goal-orientated experiments were determined. Veneer stripes of both species were compressed under two temperatures (180 and 220 °C) to characterize the stress-strain-behavior. pMDI resinated laboratory-scale boards in different design and density of both species were prepared and compared to European OSB-standards. Both species showed a specific behavior regarding the lapse of stress and strain during the compression. The physical and mechanical properties of all fabricated boards exceed the standards of conventional OSB panels except thickness swelling of panels made by 100% poplar strands at 720 g/cm^3.

Key words: Densification, European beech and polar, oriented strand boards

Introduction

Increasing demand for both residential and commercial building structures led to be the oriented strand boards as the most important option for this application throughout the world. North America and Canada are the world leaders for producing OSB. Europe market research showed that the growth of this wood based engineered panel was increased in recent years. The supply of suitable raw materials for this huge market is the big question in Europe because almost all OSB mills are based on softwoods especially Scot Pine. Therefore thinking about alternative species to supply this market would be

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necessary. The policy in Europe concentrates on hardwood forests in future. Using hardwood species could support this market and open new doors to producers. For this reason, more research and technical tests are necessary to understand which hardwood species have a potential to be an alternative for pine species in OSB manufacturing. In this study European beech and poplar as two important wood species that are available in most European countries were selected to examine the possibility of using them for building sector as OSB. The specific relationship of stress and strain for both species was examined in order to generate comprehensive knowledge for the utilization of beech and poplar as resources for wood composite manufacturing.

Materials and methods

Densification

To assess the characteristics in compression a specific mat design was developed. Veneer stripes, 1 mm thick, 20 mm wide and 350 mm long were aligned in alternating orientation in layers to form a mat of 12 mm in thickness.
One parameter was varied at a time for each mat to examine the influence of species, densification temperature and adhesive and isolate specific changes in the stress strain relationship. The list of different configurations is shown in Table 1.

Table 1. Variation of Compression Parameters

Configuration	Species	Temperature	UF-Resin
1	Beech	180°C	-
2	Beech	180°C	x
3	Beech	220°C	-
4	Beech	220°C	x
5	Poplar	180°C	-
6	Poplar	180°C	x
7	Poplar	220°C	-
8	Poplar	220°C	x

The press program was setup to densify the mat at maximum available hydraulic pressure of 25,000 kPa and aim at a target thickness of 5 mm. the initial mat thickness was 12 mm. The overall length of the press program was

340 seconds, where 10 seconds each at the beginning and ending of the densification were anticipated for the press to open and close. The change of hydraulic pressure, press platen distance and temperature were recorded by the digital control system and used for the characterization of the densification process. Stress-Strain diagrams were developed from the data sets and specific design parameters of the press.

OSB manufacturing

Small-diameter of European beech and poplar trees were harvested from Hamburg, Germany. These trees were cut to 120 cm logs suitable for knife ring flaking to produce strands. The average size of the strands was 125 mm in length, 0.6-0.7 mm in thickness and varies in width but most strands were between 20 to 40 mm. A drum blender was used to mix Poly Methylene Di-Isocyanat (pMDI) resin with strands at 5%. No wax or other additives were used. Tables 2 and 3 show the press parameters and different combinations of these panels.

Table 2. Panel fabrication parameters

Press temprature	180 °C
Press time	240 s
Thickness of board	16 mm
Face- core ratio	50-50 %
Density	650-720 g/cm^3
Strands moisture: face core	10 %
	5 %
Replication	2 boards

Table 3. Characteristics of OSB

Treatment	Panel Type	Density	Combination
A	beech	650	100%
B	beech	720	100%
C	poplar	650	100%
P	poplar	720	100%
D	b+p+b	650	25-50-25%
E	b+p+b	720	25-50-25%
H	p+b+p	650	25-50-25%
I	p+b+p	720	25-50-25%

b: beech, p: poplar

Prior to any test, the manufactured panels were conditioned at an air humidity of 65 % and temperature of 20°C for two weeks.

Modulus of elasticity (MOE), modulus of rupture (MOR), internal bond (IB) strength, thickness swelling (TS) after 24h were determined based on the EN 300 standard. From each panel three samples (370 mm by 50 mm) for bending test were used. For internal bond strength test nine 50 mm by 50 mm specimens were cut from panels. Nine 50 mm by 50 mm by 16 mm were cut for thickness swelling (in total 18 samples for each treatment). Average thickness was measured at the middle of each sample. The thickness of specimens was measured with digital caliper of 0.01 mm precision. In measurement of MOR and MOE values, a Zwick/Roell Z050 universal test device was used. In testing, the loading mechanism was operated with a velocity of 10 mm/min. The internal bond strength test was performed with a universal testing machine as well (Losenhausenwerk).

Results and discussion

Densification

Stress-Strain diagrams for the densification of both species with- and without UF resin visualize the different behavior of the species and the influence of the

additive. Beech could generally be less compressed. As shown in Figure 1 the strain at the end of the compression process is lower than the strain of poplar.
Beech reached the plastic phase after a strain of 0.2 and 0.5, whereas poplar showed a linear compression behavior in the elastic deformation phase. Poplar could be compressed to more than 50 % of the initial thickness. Beech only reached this rate for the densification without UF-resin.
Poplar was less difficult to compress and showed an elastic behavior throughout the compression process, the resin caused an elevation of stress for both species. Especially the slope of beach increased rapidly and shortened the elastic phase. This is due to the thermal curing of the resin and the fixation of the veneer stripes in the mat.
A change of the temperature from 180° C to 220° C changed the stress strain behavior of the mats during compression. While the influence on the final strain was very small, the modulus of elasticity for both species significantly changed. For poplar the slope decreased and lowered the maximum stress to nearly half the stress at 180° C.
The application of UF resin changed the stress strain behavior at 220° C compared to 180° C for beech. The elastic phase is longer with UF resin. At 220° C the stress strain behavior for poplar was nearly identical for both configurations.

In conclusion it could be confirmed that the difference in density has an influence on the stress strain behavior of both species. Beech is more difficult to compress and requires higher hydraulic pressure. Poplar in contrast is easy to compress at low pressures, causing low stress in the material.
The fixation-effect of UF-resin could be demonstrated in the stress-strain behavior. Additionally the moisture content of the mat was increased due to the resin application, resulting in a longer elastic phase making the wood more adaptive to stress during the compression.

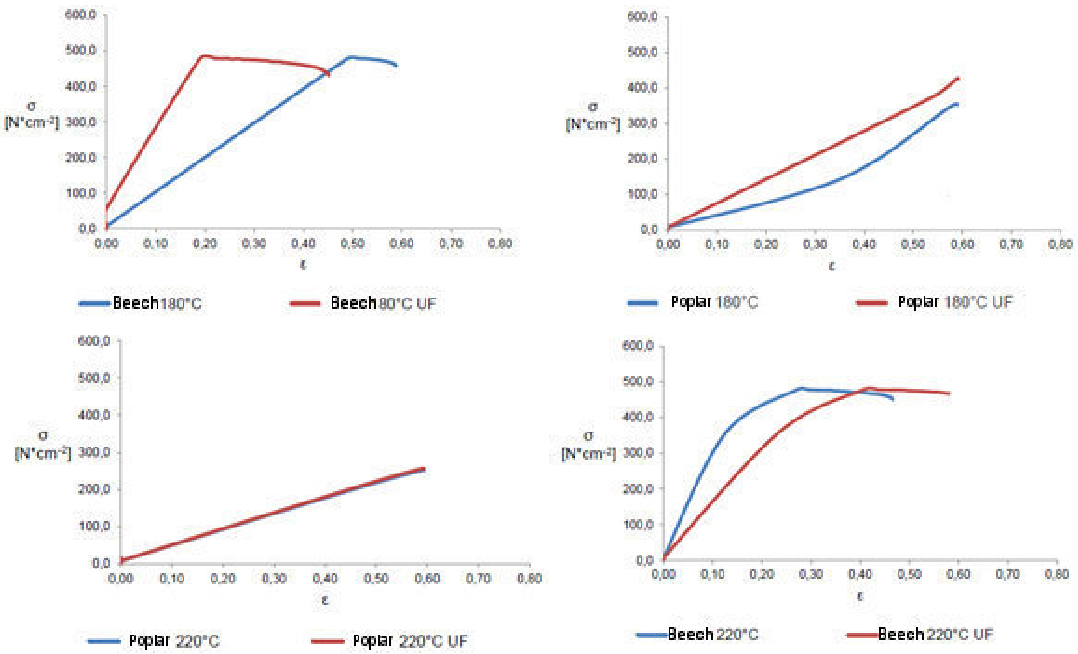


Figure 1. Stress Strain Diagrams of the Densification Experiments

OSB

The mean value and the standard deviation for modulus of rupture, modulus of elasticity and internal bond are given in Table 4. The thickness swellings of the produced panels are also available in table 4. In general with increasing density all mechanical properties and also internal bond were increased. These results agree with Chen et al (2010), Nishimura et al (2001), Vital et al (1974). Table 4 also illustrates that all properties meet the current standard of minimum requirements for OSB2 except TS for panel P.

Table 4. Average physical and mechanical properties

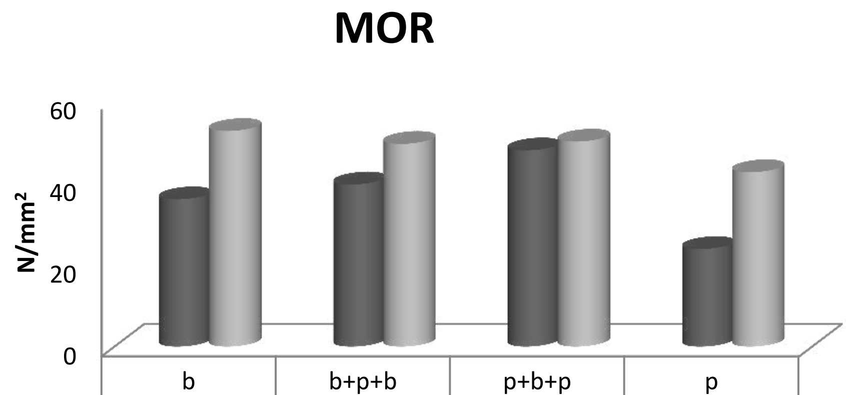
Treatment	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	TS (%)
A	35,9(4,3)	6317(200)	0,39(0,13)	16(3)
B	52,5(5,4)	6888(331)	0,77(0,08)	12(2)
C	23,8(2,8)	4980(212)	0,3(0,1)	19(3)
P	42,5(6,5)	5443(696)	0,65(0,13)	23(3)
D	39,5(5,1)	4956(211)	0,53(0,18)	12(3)
E	49,4(6,3)	5843(100)	0,56(0,8)	20(3)
H	47,8(4,1)	5310(254)	0,63(0,14)	13(3)
I	49,9(4,44)	6050(460)	0,7(0,19)	9(4)

Standard deviation in parentheses, MOR: modulus of rupture, MOE: modulus of elasticity, IB: internal bond, TS: thickness swelling after 24h

MOR and MOE

Fig 2. shows that with increasing density from 650 to 720 g/cm^3, modulus of rupture of panels made with 100% beech and poplar were increased. Because of higher density of beech strands compared to poplar, the values showed the maximum MOR reached by panels made from beech. It is well known that the bending strength dominated by the face layers. Therefore beech type panels at 720 g/cm^3 with 52.53 N/mm^2 showed the maximum MOR. Modulus of elasticity also showed the same trend as MOR.

Among the combinations of beech and poplar panels (fig 2 and 3), with increasing density the mechanical properties were improved. Although there is no big difference for MOR and MOE at 720 g/cm^3 but panels made from poplar in face layer and beech in core layer showed 72% higher MOE compare to EN300 standard for OSB type 2 which is 3500 N/mm^2.That is due to higher elastic behavior of poplar strands throughout the compression process.



	b	b+p+b	p+b+p	p
650	35,88	39,5	47,8	23,77
720	52,53	49,39	49,95	42,49

Figure 2. Effect of density and wood species on MOR

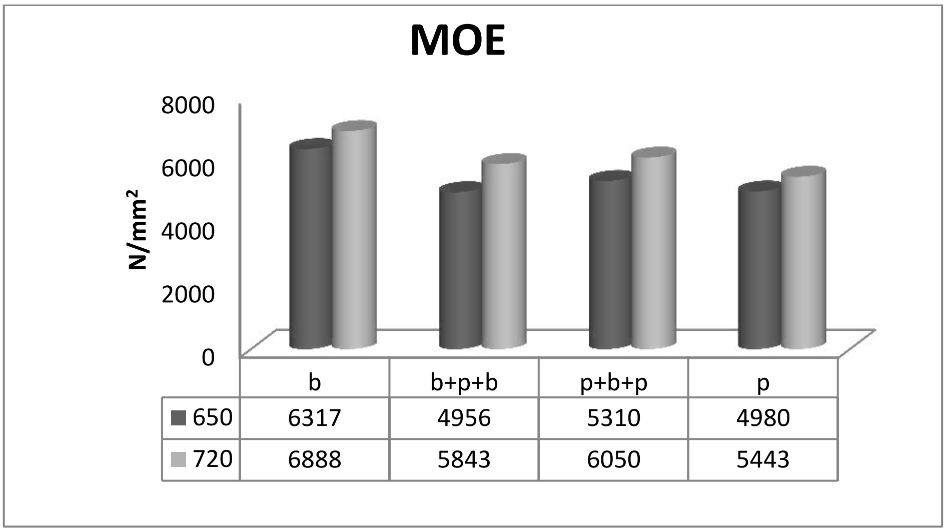


Figure 3. Effect of density and wood species on MOE

IB

In general with increasing density the internal bond as well as bending strength and modulus of elasticity was improved. This modification is more visible for pure beech and pure polar panels. In comparison between beech and polar, beech panels reached slightly higher IB. this might be related to the higher density of beech. In the presence of temperature during hot pressing, these higher density strands could be more flexible and make stronger bond with resin in the core layer. With panels made of 50% beech in the core layer (25% poplar in each faces) the same attitude was observed. These panels showed higher IB at two densities compare to panels made by 50% poplar in core layer (25% beech in each faces).

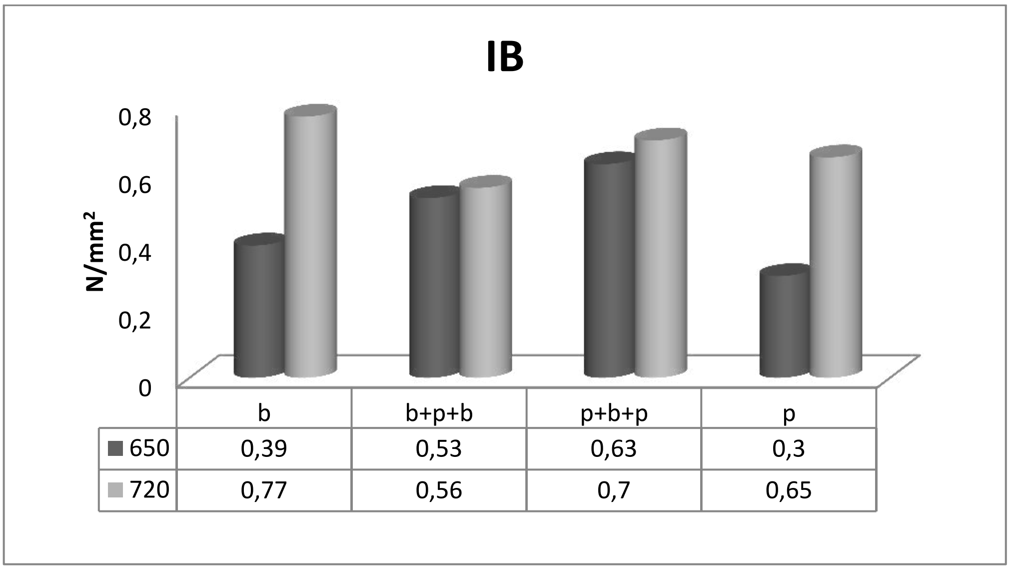
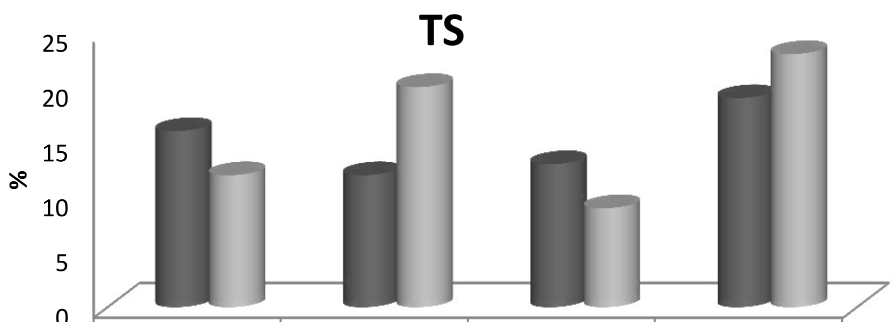


Figure 4. Average values of internal bond strength

TS

In general with increasing panel density, thickness swelling will be increased (Wu and Piao (1999, Yale1956). Thickness swelling is the biggest technical problem for wood based panels, especially OSB. The interesting point of this research was the reduction of TS for pure beech panels and also the panels made by 50% beech in core layer at higher density. Because of lower density of polar compared to beech, these strands in pure poplar panels and panels made from poplar in the core end up in higher compression during hot pressing. Therefore in the presence of water these strands have a higher ability to return to their previous position before pressing. Therefore these panels show higher TS in comparison with beech panels.



	b	b+p+b	p+b+p	p
650	16	12	13	19
720	12	20	9	23

Figure 5. Average values for thickness swelling

Conclusions

In this research densification and behavior of beech and polar veneer strands under pressure and temperature during hot pressing and physical and mechanical properties of different European beech and poplar evaluated. Based on the results of different tests for OSB-boards the following conclusions can be obtained:

a) Beech and polar are suitable timber species for OSB manufacturing

b) The minimum requirement for OSB 2 (EN300) can be fulfilled

c) Reduction of thickness swelling as the important disadvantage of OSB can be achieved with the use of beech strands in the core

d) Both species show a different densification behavior

e) Each of the species requires specific production parameters

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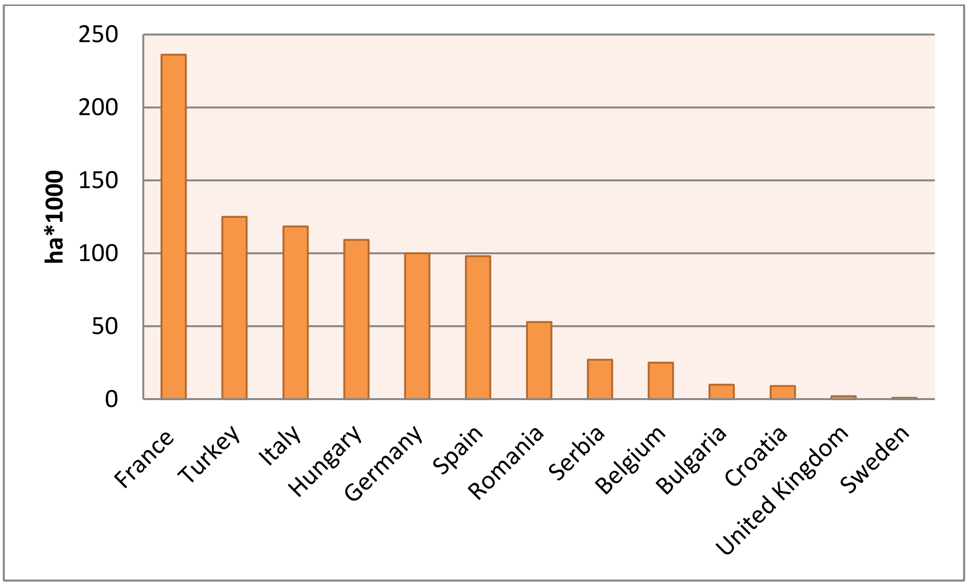
Ali Akrami

Developing of Oriented Strand Boards from European Beech and Poplar

Oriented strand boards (OSB) are one of the important engineered wood based panels for various applications such as wall and roof sheathing, flooring, packaging, and other structural applications. USA and Canada produces 83.5% of OSB in the worldwide (Thoemen, Irle, & Sernek, 2010). With 5.0 m^3/year OSB holds 7% among the wood composites in Europe. An increasing demand for housing and other construction material will lead to higher volumes. In order to meet the challenges related to volume specific properties and production costs, scientists and manufacturers are trying to develop new technologies and look for alternative raw materials for this huge market in the future.

One of the key issues today is the raw material. Almost all OSB in Europe is produced with softwood species which face an increasing competition from the energy sector. But suitable raw material and availability are two important factors for the OSB market. The 15 OSB mills in Europe which are located in different countries produce 16.5% of total OSB in the world. In particular pine is the most desirable species: the production of wood based panels and pulp and paper mainly depends on softwoods. Therefore shortage and price of pine will be two affective factors in some years and it would be an expensive commercial raw material for OSB industries. In addition due to the large amount of volatile extractives, volatile organic compound (VOC) is a major concern of products deriving from softwoods, especially Pine.

On the other side two important wood species which are available in large quantities in whole Europe are beech and poplar. Germany for example presently has 15% of the forest area covered with beech with increasing area and volume (Janssen, 2008). Small diameter logs of beech are abundant available but burned for producing energy. It easily could be converted to value-added panel products. In Europe poplar plantations cover a total area of 950.000 hectares. Graphic 1 shows the important countries having the major area of poplar planted in Europe.



Graphic 1 - Poplar planted in Europe (Coaloa & Nervo, 2011)

Furthermore poplar natural stands cover an area of 131.400 ha in Europe. They are mainly concentrated in Hungary, Spain and France.

In order to investigate the suitability of beech and poplar for OSB a research project was designed to:

1) Evaluate the possibility of using European beech and poplar as raw materials for OSB panels and develop OSB from these species with high mechanical properties for the building sector and even light weight OSB for furniture or similar uses and

2) Compare the properties of OSB made of beech and poplar with conventionally made OSB.

In this research after debarking the logs and preparing strands by laboratory knife ring flaker, the beech and poplar strands were prepared for three different combinations (25/75-50/50-60/40 face-core ratio), with target panel densities of 0.65 and 0.72 g/cm^3 and using Polymeric Methylene Diphenyl Diisocyanate (PMDI) resin as the adhesive. The hand-formed resinated strand mats (600*550*16 mm) were pressed using a Siempelkamp press in the lab. All test samples were conditioned at 65% RH and 25° C then physical and mechanical properties such as modulus of rupture and modulus of elasticity, internal bond strength, and thickness swelling after 24h were measured and compared to Standard European OSB.

The primary results indicated that pure beech and poplar panels as well as different combinations could be a powerful rival for Pine OSB. All mechanical properties and the internal bond do not only reach the minimum requirement of OSB2 in EN300: some combinations exceed the requirement by 30 to 70%. In case of physical properties, all TS values were lower than required by EN standard which is 20% for OSB2 except of pure poplar and panels made by 75% poplar in core layer for 0.720 g/cm^3 density. The results of this work will open new doors for hardwoods especially European beech and poplar to create a new raw material market for OSB in Europe.

The next steps of this study are predefined by two important aspects. First using fine material for the core layer and evaluating its effect on properties of OSB. During flaking process, generating fine materials is inevitable. Therefore using this kind of material in core layer can decrease the production costs. Second, today volatile organic compounds play important role in Europe. Further investigation will be made to determine the effect of European Beech and Poplar on the emission of VOC's.

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Declaration

In line with the regulations on dissertations of the Department of Biology, University of Hamburg I hereby declare that I have done the present work by myself, not used other than the stated sources and aids, that any used statement from literature is noted and that I have listed all third party help.

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17.07.2014