Project co-funded by the European Commission within the FP7 (2007–2013)

Grant agreement no.: 308630

I-PAN

INNOVATIVE POPLAR LOW DENSITY STRUCTURAL PANEL

Project type: Collaborative Project

Start date of project: 1st October 2012 Duration: 36 months

D3.1 Prior art study with set of target resin properties

WP n° and title	WP3 - Resin innovation for solvent and formaldehyde reduction
WP leader	CHIMAR
Responsible Author(s)	CHIMAR
Contributor(s)	IMAL, IBL
Planned delivery date	M9 (06/2013)
Actual delivery date	M9 (06/2013)
Reporting period	RP1

Dissemination Level		
PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Document information

Abstract

I-PAN project aims at providing novel and environmentally friendly solutions in the field of the engineered wood (EW) panels and particularly by innovating in Oriented Strands Board (OSB) manufacturing process to reach higher level functional characteristic of Lightweight Strand Board (LSB). OSB/LSB is an engineered wood-based panel consisting of strands of wood pressed together in layers and bonded with a synthetic resin. The wood species used in OSB manufacture include both softwood and hardwood. The resin types typically used include Phenol formaldehyde (PF), Melamine fortified Urea Formaldehyde (MUF) or isocyanate (pMDI). This document is the report of prior art study for formaldehyde-based resins used in binding recycled wood and/or poplar wood species.

Keywords

Poplar, wood, OSB, wood-based panels, engineered wood, binder, adhesive

Authors

Editor(s)	Paschalis Tsirogiannis, Eleftheria Athanassiadou
Contributors	IMAL, IBL
Peer Reviewers	CTECH, ECSC

Document history

Version	Date	Reviewed paragraphs	Short description
0.1	*25/06/2013*	*All*	*Draft release for peer review*
1.0	*29/06/2013*	*All*	*Final version for the EC*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS AND DEFINITIONS

Table 1 - List of abbreviations

OSB	Oriented Strand Board
LSB	Lightweight Strand Board
UF	Urea Formaldehyde
PF	Phenol formaldehyde
MUF	Melamine Urea Formaldehyde
pMDI	Polymeric Methylene Diphenyl Diisocyanate

1 INTRODUCTION

I-PAN project aims at providing novel and environmentally friendly solutions in the field of the engineered wood (EW) panels and particularly by innovating in Oriented Strands Board (OSB) manufacturing process to reach higher level functional characteristic of Lightweight Strand Board (LSB). OSB/LSB is an engineered wood-based panel consisting of strands of wood pressed together in layers and bonded with a synthetic resin. The wood species used in OSB manufacture include both softwood and hardwood. The resin types typically used include Phenol formaldehyde (PF), Melamine fortified Urea Formaldehyde (MUF) or isocyanate (pMDI). This document is the report of prior art study for formaldehyde-based resins used in binding recycled wood and/or poplar wood species.

1.1 AIM AND GOALS OF I-PAN PROJECT

I-PAN project aims at providing novel and highly environmental friendly solutions in the field of engineering wood (EW) based boards.

The main challenge for the light wood-based panel industry is to reach higher level functional characteristic of Lightweight Strand Board (LSB) by engineering traditional wood based panels through innovation in Oriented Strands Board (OSB) manufacturing process as well as by continuously increasing the efforts to manage and use valuable resources in a sustainable manner throughout the entire life-cycle. Recovery and recycling of wood residues also forms an integral part of the eco-efficient utilization of resources.

The I-PAN project (1) will develop and demonstrate the environmental benefits brought by its advanced solutions by:

- reducing the pressure on forests derived raw materials use, thanks to the maximization of use of selected poplar plantations allowing 7-8 years poplar growth cycle;
- reducing the quantity of wood as a input of the overall process, thanks to the use of 50% made of re-cycled wood;
- reducing the wastes and consumptions along the overall manufacturing process, starting from an optimal use of raw material to the several steps needed for wood treatment and final product release;
- reducing the quantity and presence of hazardous and volatile chemicals by developing a new formaldehyde-based resin suitable for the necessary bonding recycled wood;
- reducing the carbon footprint by innovating the production process and decreasing the number of felled trees;
- enhancing the EU competitiveness in the eco-friendly global market.

1.2 Oriented Strand Board

The following section provides some detailed information on OSB (2).

1.2.1 Description

OSB (Oriented Strand Board) is an engineered wood-based panel consisting of strands of wood which are bonded together with a synthetic resin; the strands are pressed together in layers. In the outer layers strands are generally oriented longitudinally in line with the panel length, whereas in the middle layers strands generally lie in a cross wise direction.

1.2.2 Composition

The wood species used in OSB manufacture include both softwoods (spruce, pine) and some hardwood. Wood strands are cut tangentially from debarked logs which are held longitudinally against rotating knives. The ribbon of strands produced is usually about 75 mm wide and this breaks up on handling to produce individual strands which are typically 100 mm along the grain and from 5 to 50 mm across the grain.

After drying, these strands are sprayed with a synthetic resin binder. The resin types typically used include Phenol formaldehyde (PF), melamine fortified Urea Formaldehyde (MUF) or isocyanate (PMDI), all of which are moisture resistant binders. In Europe, it is common to use a combination of binders, typically PMDI would be used in the core and MUF in the face layers and this has the advantage of reducing press cycles whilst imparting a bright appearance to the surface of the panel.

1.2.3 Appearance

OSB is readily identified by its relatively large and long wood strands. The orientation of the surface strands is not always visually apparent, especially in small cut pieces of panel. The main merits of OSB lie in the field of its mechanical performance, which is directly related to the geometry of the strands and their orientation within the panel. Although OSB is made up of relatively large strands of wood, its surface is relatively smooth and this can be further enhanced by sanding without loosing the aesthetic character which is unique to OSB.

OSB varies in colour from a light straw colour to a medium brown depending on wood species used, resin system adopted and pressing conditions employed. It contains no knotholes, core voids or points of weakness.

1.2.4 Density, mass and sheet size

Panel density (and thus panel mass) varies depending upon the product, being affected by the timber species and the manufacturing process. Typical densities are 600-680kg/m. Thus, for example, a 2400 x 1200 x 12mm panel will weigh approximately 20 kg.

Panel sizes commonly available are 2440mm x 1200mm, 2440mm x 1220mm and 2500mm x 1250mm in thicknesses of 6mm to 40mm. Other sizes are available or can be produced to order. Panels are produced with either square or tongued & grooved (T&G) edges.

1.2.5 Applications

Due to its high mechanical properties and the orientation of the strands within panels, OSB is particularly suitable for load-bearing applications in construction and is widely used for flooring, roof decking and wall sheathing, but there is also a wide field of other applications where OSB as a wood-based panel product can be utilised. Different grades of the product are available for different levels of loading and different environmental conditions. Guidance on the use of OSB in these load-bearing applications is given in ENV 12872 and EN 13986. OSB is a quality, precision-engineered product that can satisfy the same applications and loading conditions as plywood and in some cases a thinner OSB panel may be used thereby reducing costs. Large quantities of OSB are also used for sarking and industrial packaging and in site hoardings and pallet tops.

1.2.6 Specification

Manufacturers shall demonstrate compliance with the legal requirements by showing that their OSB complies with the harmonised standard EN 13986 "Wood-based panels for use in construction - Characteristics, evaluation of conformity and marking". It calls up EN 300 "Oriented Strand Boards (OSB) - Definitions, classification and specifications", which will have to be used when specifying OSB.

Four grades of OSB are defined in EN 300 in terms of their mechanical performance and relative resistance to moisture. These are:

- OSB/1 - General purpose boards and boards for interior fitments (including furniture) for use in dry conditions.
- OSB/2 - Load-bearing boards for use in dry conditions.
- OSB/3 - Load-bearing boards for use in humid conditions.
- OSB/4 - Heavy-duty load-bearing boards for use in humid conditions.

1.2.7 Mechanical properties

The threshold value requirements for specified mechanical properties of the 4 OSB grades in EN 300 can be summarised as indicated in the following tables. The values are 95 percentiles (5 percentile values in the case of swelling in thickness) and are characterised by a moisture content in the material corresponding to a relative humidity of 65% and a temperature of 20°C. This implies that these specified mechanical properties have to be controlled according to statistical principles and that 95% of the test values on individual samples have to exceed (or remain below in the case of swelling in thickness) the respective threshold value requirement in EN 300.

Table 2: Threshold value requirements for OSB/1

Property	Test method	Unit	Requirement		
			Thickness range (mm, nominal)		
			6 to 10	> 10 and < 18	18 to 25
Bending strength - major axis	EN 310	N/mm2	20	18	16
Bending strength - minor axis	EN 310	N/mm2	10	9	8
Modulus of elasticity in bending - major axis	EN 310	N/mm2	2500	2500	2500
Modulus of elasticity in bending - minor axis	EN 310	N/mm2	1200	1200	1200
Internal bond	EN 319	N/mm2	0.30	0.28	0.26
Swelling in thickness - 24 h	EN 317	%	25	25	25

Table 3: Threshold value requirements for OSB/2

Property	Test method	Unit	Requirement		
			Thickness range (mm, nominal)		
			6 to 10	> 10 and < 18	18 to 25
Bending strength - major axis	EN 310	N/mm2	22	20	18
Bending strength - minor axis	EN 310	N/mm2	11	10	9
Modulus of elasticity in bending - major axis	EN 310	N/mm2	3500	3500	3500
Modulus of elasticity in bending - minor axis	EN 310	N/mm2	1400	1400	1400
Internal bond	EN 319	N/mm2	0.34	0.32	0.30
Swelling in thickness - 24 h	EN 317	%	20	20	20

Table 4: Threshold value requirements for OSB/3

Property	Test method	Unit	Requirement		
			Thickness range (mm, nominal)		
			6 to 10	> 10 and < 18	18 to 25
Bending strength - major axis	EN 310	N/mm2	22	20	18
Bending strength - minor axis	EN 310	N/mm2	11	10	9
Modulus of elasticity in bending - major axis	EN 310	N/mm2	3500	3500	3500
Modulus of elasticity in bending - minor axis	EN 310	N/mm2	1400	1400	1400
Internal bond	EN 319	N/mm2	0.34	0.32	0.30
Swelling in thickness in 24h	EN 317	%	15	15	15
Requirements for moisture resistance					
Bending strength after cyclic test - major axis	EN 321+ EN 310	N/mm2	9	8	7
OPTION 1 Internal bond after cyclic test	EN 321+ EN 319	N/mm2	0.18	0.15	0.13
OPTION 2 Internal bond after boil test	EN 1087-1+ EN 319	N/mm2	0.15	0.13	0.12

Table 5: Threshold value requirements for OSB/4

Property	Test method	Unit	Requirement		
			Thickness range (mm, nominal)		
			6 to 10	> 10 and < 18	18 to 25
Bending strength -major axis	EN 310	N/mm2	30	28	26
Bending strength -minor axis	EN 310	N/mm2	16	15	14
Modulus of elasticity in bending - major axis	EN 310	N/mm2	4800	4800	4800
Modulus of elasticity in bending - minor axis	EN 310	N/mm2	1900	1900	1900
Internal bond	EN 319	N/mm2	0.50	0.45	0.40
Swelling in thickness - 24 h	EN 317	%	12	12	12
Requirements for moisture resistance					
Bending strength after cyclic test - major axis	EN 321 + EN 310	N/mm2	15	14	13
OPTION 1 Internal bond after cyclic test	EN 321 +EN 319	N/mm2	0.21	0.17	0.15
OPTION 2 Internal bond after boil test	EN 1087-1 +EN 319	N/mm2	0.17	0.15	0.13

2 Binders for Wood Composite Industry- OSB

As stated in section 1, three types of binders are most commonly used for OSB and other wood composite panels. A short description of each category is demonstrated below:

2.1. Melamine fortified Urea Formaldehyde Resin

Melamine-Urea- Formaldehyde (MUF) resins are considered as co-polymers of melamine, urea, with formaldehyde. The quantity of the melamine is above 10% calculated on a liquid basis. These resin types exhibit high water and weather resistance and they are usually used for the production of highly moisture resistant boards are applied in the production of panels for exterior use or in conditions of high humidity.

Melamine-urea-formaldehyde resins are among the most used adhesives for exterior and semi-exterior wood panels. Their much higher resistance to water attack is their main distinguishing characteristic from UF resins. Notwithstanding their widespread use and economic importance, the literature on melamine resins is only a small fraction of that dedicated to UF resins. Often, MFs and MUFs are described in the literature only as a subset of UF amino resins (3). In this application their handling is very similar to that of UF resins for the same use, with the added advantage of excellent water and weather resistance. MUF resins produce high-quality wood composite boards because their adhesive joints are boilproof. Considerable discussion has occurred and many investigations have been carried out on the weather resistance these adhesives. Many authors uphold the good weather resistance of the more recently developed MUF adhesives, especially those in which small amounts of phenol have been incorporated (3).

2.2 Phenol Formaldehyde

Phenol formaldehyde resins (PF) are synthetic polymers obtained by the reaction of phenol or substituted phenol with formaldehyde. They are better known however for the production of molded products including pool balls, laboratory countertops, and as coatings and adhesives. In the form of Bakelite, they are the earliest commercial synthetic resin (4).

Phenolic resins are also the oldest synthetic polymers used in the wood – based industry. Having excellent long term water, weather and high temperature resistance, these resin types serve as the only choice for the production of plywood and OSB for exterior use or in heavy humid conditions.

Base-catalysed phenol-formaldehyde resins are made with a formaldehyde to phenol ratio of greater than one (usually around 1.5). These resins are called resoles and, being thermosets, will crosslink on heating to around 120 °C to form methylene and methyl ether bridges through eliminating water molecules. The high crosslinking gives this type of phenolic resin its hardness, good thermal stability, and chemical imperviousness. Resols are referred to as "one step" resins as they cure without a cross linker. Resoles are major polymeric resin materials widely used for gluing and bonding building materials. Exterior plywood, oriented strand boards (OSB), engineered laminated composite lumber (LCL) are typical applications.

2.3. PMDI

Methylene diphenyl diisocyanate, most often abbreviated as MDI, is an aromatic diisocyanate. MDI reacts with polyols in the manufacture of polyurethane. It is the most produced diisocyanate, accounting for 61.3% of the global market in the year 2000. The first step of MDI is the reaction of aniline and formaldehyde, using hydrochloric acid as a catalyst to produce a diamine precursor. Then, these diamines are treated with phosgene to form an MDI and hydrochloric acid. Distillation of the MDI mixture gives Polymeric MDI and EMDI, an emulsion of PMDI in water.

Isocyanate resins were developed during World War II and quickly became known as adhesives that can bond ''anything to anything''. Since they were first introduced to the German particleboard market in the early 1970s, the use of MDI (4,4'-methylene diphenyl isocyanate) binders in composite panels has grown significantly. Now, MDI binders are used in over 20 percent of the high growth OSB (oriented strand board) industry worldwide and are in routine production in MDF (medium density fiberboard) mills in Europe and North America. Like traditional formaldehyde-based resins, MDI is a synthetic chemical. MDI binders are unique in that they seek out and react with both the moisture in the material, and the hydroxyl groups, which make up the lignocellulosic furnish. The result is not just a mechanical bond, but a tough, water-resistant chemical bond that creates the classic benefits of MDI-bonded composite panels: low resin dosage; extreme moisture resistance; low swelling; and high strength (5).

3 Patent Search

During the research executed for this study, no publications were found on resins and binder systems neither specifically for recycled wood nor for poplar wood. Nevertheless, information can be taken from similar tasks of the prior art.

In the examples included in the European Patent of Enigma N.V with title: "Production of high added value products from wastes" (6), the treated recycled wood replaced 50 to 60% of fresh wood and it was bound with standard commercial urea formaldehyde resin. The treatment described was with steam and chemicals in the digester of an MDF plant. It is worth mentioning that the chemicals used assisted in formaldehyde content reduction when determined by using the perforator method.

On the other hand, the difficulty of binding highly porous wood, including poplar, has been identified and treated with solvent-born adhesive in the US patent of Valspar Sourcing, Inc. with title: "Low penetration low formaldehyde alkyd composition" (7). More specifically, the high porosity of end grain of various wood species such as alder, birch, pine, poplar, and soft maple, is reduced with the use of coconut oil alkyd melamine resin, a melamine-formaldehyde cross-linker and various additives mostly for appearance improvement. The currier is a mixture of volatile ketones.

The effect of the raw wood density is taken into account for the production of light-weighted particleboard under the Japanese Patent JP 06031708. Although the document of this patent was not available, the BASF EU patent "Light wood materials with good mechanical characteristics and method of producing the same" (8) quotes from the Japanese document that "that the specific density of the wood particles should not exceed a value of 0.5 g/cm^3". The aforementioned BASF patent claims the production of light OSB boards using common wood species in combination with expanded polystyrene (co)polymers used as filler(s). All commercial binders for wood-composite boards are claimed that can be used, while in the examples demonstrated, UF resin was utilised. In another BASF patent with title:" Lightweight wooden materials with good mechanical properties and low formaldehyde emission" (9) a combination of UF and pMDI is used to bind wood particles and polystyrene spheres.

A similar technique but with different fillers is described in the US patent:" Strength-enhanced, lightweight lignocellulosic composite board materials and methods of their manufacture" (10) for producing light OSB. In this patent, belonging to J.M. Huber Corporation, hollow glass, ceramic and polymeric fillers were used to achieve the low density (~615kg/m^3) and 3.5% pMDI was used in as a binder.

Particularly low density oriented strand boards (450-550kg/m^3) claimed that can be produced when following the method described in EU patent of Alberta Research Council with title:" Low density oriented strand boards" (11). The innovation claimed is that a high moisture content core layer (20%) is hot pressed; the steam generated during heating of the mat, creates voids, resulting the low density. Again, in the provided examples, 4% pMDI was used as a binder.

In US patent with title: ” Bonding wood composites with resin solids-fortified phenol-formaldehyde resin” (12) of Georgia-Pacific LLC, the addition of up to 10% (mostly)spray-dried PF resin in liquid PF is claimed to assist on the bonding of OSB and other woodbased panels. The explanation atempted in the patent is that spray-dried PF resin particles have water-repelant properties that keep the particles in susspension without allowing them to disolve. Therefore, high active solids content PF resin is achieved.

4 Bibliography

1. I-PAN Aim & Goals. *www.ipanproject.eu.* [Online] [Cited: March 1, 2013.] http://www.ipanproject.eu/project/aim-goals/.

2. **www.osb-info.org, www.antilope.be.** Technical Information. *www.osb-info.org.* [Online] EPF. [Cited: March 1, 2013.] www.osb-info.org.

3. **Pizzi, A.** *Advanced wood adhesives technology.* New York : Marcel Dekker Inc., 1994. 0-8247-9266-1.

4. Phenol formaldehyde resin. *Wikipedia, the free encyclopedia.* [Online] [Cited: March 1, 2013.] http://en.wikipedia.org/wiki/Phenol_formaldehyde_resin.

5. **Papadopoulos, A. N., et al., et al.** Isocyanate Resins for Particleboard: PMDI vs EMDI. *Holz als Roh- und Werkstoff.* 2002, 1.2.2002.

6. **Athanassiadou, Eleftheria, Nakos, Panagiotis and Coutinho, Aires Manuel Joao.** *Production of high added value products from wastes. EP 1255630 B1* May 17, 2004.

7. **Wu, Shaobing, Melnyk, Thomas J. and Hale, William E.** *Low penetration low formaldehyde alkyd composition. US 8337995 B2* December 25, 2012.

8. **Auenmüller, Jürgen von, et al., et al.** *Light wood materials with good mechanical characteristics and method of producing the same. EP 2083975 B1* December 29, 2010.

9. **Finkenauer, Michael, et al., et al.** *Lightweight wooden materials with good mechanical properties and low formaldehyde emission. EP 2042560 A1* April 1, 2009.

10. **Liu, Feipeng, Peek, Brian M. and Flaherty, Kelly R.** *Strength-enhanced, lightweight lignocellulosic composite board materials and methods of their manufacture. US7217458 B2* May 17, 2007.

11. **Sean, Sy Trek and Brunette, Gilles.** *Low density oriented strand boards. US6767490* July 27, 2004.

12. **Brehmer, JR. Harmon E., et al., et al.** *Bonding wood composites with resin solids-fortified phenol-formaldehyde resin. US8252427 B2* August 28, 2012.