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Produktion av miljöanpassade spånplattor från träavfall

Manufacturing of environmentally friendly particleboards from wood waste

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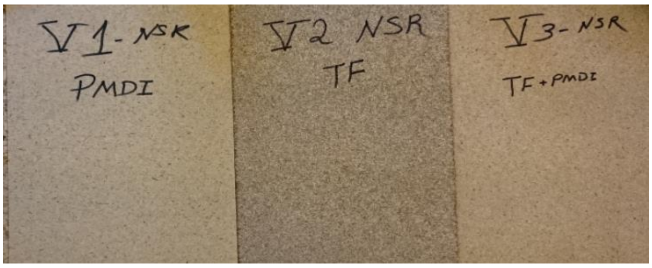

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Preface

The pre-project *“Manufacturing of environmentally friendly particleboards from wood waste”* has been financed through funding from RE: Source and Nordvästra Skånes Renhållnings AB (NSR).

The research work was initiated and led by Dr Prof Mahmood Hameed, Academic Advisor at NSR and carried out in cooperation between Lund University, NSR (waste wood processing) and the Georg August University of Göttingen, Germany (mechanical and environmental tests of produced models of particle boards). Eric Rönnols, Rönnols Miljökonsult AB (Senior Advisor at NSR), has served as an administrative project leader.

Project title - Swedish Produktion av miljöanpassade spånplattor från träavfall
Project title – English Manufacturing of environmentally friendly particleboards from wood waste
Company Nordvästra Skånes Renhållnings AB
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Key words Wood waste, particleboards, tannin, formaldehyde, PMDI, environmentally friendly product

The project has been followed by a reference group with participation from NSR, Municipality of Båstad, the University of Lund and Ikea Industry Hultsfred (as a manufacturer of particleboards):

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Sammanfattning

Projektidén har varit att undersöka möjligheterna att utnyttja träavfall och miljövänliga bindemedel för att producera spånskivor med mekaniska egenskaper som uppfyller kraven enligt existerande standarder och har bättre miljömässiga egenskaper än konventionellt framställda spånskivor.

Svenskt träavfall, ca 1,7 miljoner ton/år (SCB, 2016) utnyttjas idag i princip enbart som biobränsle. Spånplattor tillverkas av jungfruligt virke och biprodukter (spån m m) från trävaruindustrin. Bindemedlen baseras huvudsakligen på formaldehyd, som i sin tur orsaker vissa utsläpp från den färdiga produkten.

På NSR, Helsingborg omvandlas 25 000 – 30 000 ton träavfall årligen till trächips som utnyttjas som bränsle för fjärrvärmeproduktion. I projektet har visats att efter vissa mindre ändringar i sorteringsrutiner hos avfallsproducenten och/eller på avfallsanläggningen kan nuvarande, flexibla utrustning för krossning, metallseparering och siktning även utnyttjas för produktion av basmaterial för tillverkning av spånskivor.

Ett utnyttjande av träavfallet som råmaterial innebär ett steg upp i avfallshierarkin - förstudien visar att tillverkning av spånplattor kan vara en möjlig väg även kommersiellt för att nå detta mål.

I förstudien har det genom praktiska försök visats att det är möjligt att tillverka tre-lagers spånskivor från bearbetat träavfall, bundna med tannin-harts och PMDI. Såväl de mekaniska egenskaperna som emissionen av formaldehyd från de tillverkade modellerna klarar gällande EU-standard EN 312 och kraven för användning i bl a invändiga bygg-konstruktioner och möbler under torra förhållanden (Typ P2). Genom att ersätta 25 % av PMDI med tannin-harts som bindemedel kan kostnaderna för bindemedel minska i storleksordningen 10-15 %.

De ekonomiska och kommersiella effekterna av att utnyttja träavfall från avfallsanläggningar och alternativa bindemedel som råvaror för produktion av spånplattor behöver utredas vidare.

Miljömässigt innebär användningen av träavfall på det sätt som testats i projektet att organiskt kol ackumuleras i produkter i stället för att emitteras som koldioxid. Materialåtervinning skapar en ”kolsänka” och bidrar till begränsa växthuseffekten och den pågående globala uppvärmningen.

Ytterligare studier krävs för att testa och utvärdera ett antal möjliga kombinationer av bindemedel (bl a albuminer, tanniner och andra fossilfria alternativ) och olika kvaliteter av träavfall för att hitta de bästa tekniska, miljömässiga och ekonomiska lösningarna för en kommersiell produktion av hållbara spånplattor.

Summary

The project idea is to produce innovative models of particleboards from wood waste, using alternative binders and compare the mechanical and environmental properties of the products with existing standards and conventional particleboards.

Wood waste in Sweden, approx. 1,7 million tons/year (SCB, 2016), is today used as a biofuel – hardly anything of the waste wood is recovered as material. At the same time virgin wood is the prime raw material for production of particleboards. Adhesives used in the particleboard industries normally contains formaldehyde, which is then as a consequence slowly emitted from products made by particleboards.

At NSR Recycling facility in Helsingborg wood waste has been sorted and processed using flexible machinery used at the facility (crusher, magnetic separation units and drum sieves). It has been concluded that only slight changes in sorting routines and conventional crushing and sieving gives a wood chip quality suitable for the particleboard industry.

Using wood waste as raw material for manufacturing particleboards contributes to the environmental goals regarding increased recovery of material (a step up in the waste hierarchy). The pre-study indicates possibilities to develop commercial methods for recycling of wood waste.

The pre-study has demonstrated for the first time the possibility of manufacturing three-layers TF-resin and PMDI-bonded particleboards from processed unpainted wood waste. The physical- and mechanical properties as well as the level of emissions of extractable formaldehyde from the manufactured models of particleboard complied with the specifications of European standard EN 312 (2010) and fulfilled the requirement for interior fitments (including furniture) for use in dry conditions (Type P2).

Substituting PMDI with tannin resin as tested in the pre-study could reduce the adhesives cost with 10-15 %.

The economic/commercial effects of using wood waste from municipal waste management plants as raw material for and changing adhesives has to be further investigated.

The use of wood waste as raw material for production of particle boards would contribute to an important accumulation of organic carbon in Sweden. The creation of such a “carbon sink” means a decrease of carbon dioxide emissions and thereby contributing to mitigate the greenhouse effect and the growing problem of global warming.

Further studies are needed to test and evaluate a number of combinations of binders (including albumins, tannin and other fossil free adhesives) and waste materials to find the best technical, environmental and economic solutions for a future, commercial production of sustainable particleboards.

Introduction and background

Wood waste as a resource

The amount of wood waste in Sweden 2014 was about 1,7 million tons (SCB, 2016), which is equivalent to approx. 5,7 million m^3 of wood chips with a density of 290 kg/ton (Avfall Sverige 2000). 90 % of the wood waste was used as biofuel for heat and/or production of electricity.

Table 1 Treatment of wood waste (non-hazardous waste) in Sweden, 2010, 2012 and 2014, tons/year

Treatment method	**2010**	**2012**	**2014**
Composting and anaerobic digestion	65 700	49 900	25 600
Backfilling	1 360	0	0
Reuse, including capping of landfills	26 300	8 350	4 390
Use as biofuel	1 320 000	1 144 000	1 556 000
Landfilling	60	6 460	4 390
Pretreatment and sorting	480	12 300	128 000
Total, treated non hazardous wood waste	**1 413 900**	**1 221 010**	**1 718 380**

Source: SCB, Officiell statistik, statistikdatabasen, 2016

According to FAO "Yearbook of forest product", 2013, the amount of wood residues in Sweden was 5 900 000 m^3 and in Europe 63 074 000 m^3 (FAO, 2013).

Moreover, Sweden's consumption of particleboard 914 000 m^3 is more than its production 483 000 m^3 (FAO, 2013). Therefore, it is interesting to investigate the possibilities to manufacture particleboards from wood waste. The particleboards have to comply with the European norms.

Environmental impact

Changing the use of wood waste from energy recovery to material recovery would also imply an accumulation of organic carbon and thus mitigation of the greenhouse effect and the growing problem of global warming.

Urea-formaldehyde adhesives are the most commonly used resins for conventional particleboard manufacturing in Europe, northern Europe and USA. To decrease the formaldehyde release addition of formaldehyde scavenger and catalysator is required. Alternatively, nontoxic and more environmentally friendly products made from renewable or recyclable resources are becoming more widely used (Spiegel and Meadows, 1999; Hameed, 2015; Hameed *et. al.*, 2005). Using these alternatives is one step towards a more sustainable use of earth's resources.

It is also important to characterize the formaldehyde release from particleboards manufactured by using different adhesives like Tannin Formaldehyde (TF-resin: natural binders) and Polymers based on Diphenylmethane-diisocyanate (PMDI), which bind wood without adding any formaldehyde scavenger or catalysator (urea, melamine, resorcinol).

Earlier research

Particleboard is one of the common materials used in building construction and serves numerous functions as cabinetry, tabletops, shelving wall and floor panels, door and furniture (Deppe and Ernst, 1992; Hygreen *et. al.*, 2003). One of the major challenges is to produce boards with low formaldehyde emissions. Formaldehyde is a volatile compound released from particleboards into the air. Exposure to formaldehyde in concentration greater than 0.1 part per million (ppm) can cause nasal and throat congestion, burning eyes, headaches as well as cancer (see Roffael, 1993).

Alternatives to Urea-Formaldehyde bonded particleboards are Tannin Formaldehyde resin bonded particleboard and Polymeric Diphenylmethane-diisocyanate bonded particleboards, which can help reduce and eliminate the formaldehyde emission into the air. Some research related to this topic, which focused on manufacturing Urea-Formaldehyde bonded particleboard from agricultural wastes as well as from harmful invasive plants as environmentally friendly products has been carried out. Hameed (2007, 2008) published work related to the possibility of manufacturing Urea- Formaldehyde bonded particleboard as well as medium density fiberboard from cotton stems.

Mosseily and Hameed (2012) demonstrated the possibility of producing Urea-Formaldehyde particleboard as a by-product of olives. Hameed (2012) explored the possibility of manufacturing Urea- Formaldehyde particleboard from pruning wastes of olive trees. Nasser (2012) researched the feasibility of using tree pruning of seven wood species to manufacture three-layer Urea- Formaldehyde bonded particleboard. Al-Sawaf and Hameed (2013) investigated the possibility of manufacturing Urea- Formaldehyde bonded medium density fiber boards from Cotton Seeds hulls as a waste by-product of cotton oil. Abo Saeed (2013) studied the possibility of producing Urea- Formaldehyde bonded particleboard from Chinese Sumach woods (*Ailanthus glandulosa* Desf.) as an invasive plant. Essa (2012) determined the formaldehyde emission from Urea- Formaldehyde bonded particleboard and medium density fiberboard imported from Europe.

Comparatively little researches work related to the possibility of manufacturing Tannin Formaldehyde resin or Polymeric Diphenylmethane-diisocyanate bonded particleboards from wood waste is published (Rosamah, 2003; Bisanda *et. al.*, 2003; Zwang *et. al.*, 2004; Moa *et. al.*, 2011; Noman *et. al*., 2014).

The possibility of manufacturing particleboards bonded by a combination of Tannin Formaldehyde resin and Polymeric Diphenylmethane-diisocyanate from wood wastes has not yet been investigated.

Project objectives

1- Developing commercial methods for recycling of wood waste as well as increasing the efficiency of wood waste recycling at waste treatment plants.

2- Contribute to a decrease in emissions of greenhouse gases, through manufacturing innovative models of particleboards from wood wastes.

3- Investigate the possibility of manufacturing innovative and environmentally friendly models of Tannin Formaldehyde resin (TF-resin) bonded particleboard, Polymeric Diphenylmethane-diisocyanate (PMDI) bonded particleboard and TF-resin, PMDI-bonded particleboard from wood waste in accordance with European Norms.

4- Determine the emission of formaldehyde from particleboards bonded with environmentally friendly adhesives: Tannin Formaldehyde, Polymeric Diphenylmethane-diisocyanate (PMDI) and a mixture of TF-resin and PMDI.

5- Determine the level of organic carbon being “captured” by particleboard manufacturing from the wood wastes in Sweden.

6- Contribute to the achievement of the national objectives of the Convention on climate change (UNFCCC, 1992).

7- Create a basis to formulate a major, innovation project.

Project Implementation

The project has included the following tasks:

1- Collection of data about waste wood amounts in Sweden and Europe,

2- Contacts with particleboard producers,

3- Characterizing of wood waste from NSR

4- Preparation of wood chips suitable for manufacturing of particleboards,

5- Manufacturing of three models of particleboards from wood waste,

6- Determination of physical and mechanical properties of the manufactured particleboards,

7- Determination of formaldehyde release from the manufactured particleboards,

8- Determination of the possible accumulation of organic carbon through production of particleboards from waste wood.

Collection of data and contacts with producers has been performed mainly by prof Hameed, NSR, and prof Torleif Bramryd, University of Lund. The general characterization of the NSR wood waste was performed by prof Hameed.

Preparation of wood chips from the collected waste was done by NSR waste management personnel at the recycling site in Helsingborg. The machinery used was a CBI Magnum Force 6400 crusher equipped with magnetic separator and a Doppstadt SM-518 drum sift equipped with rotary changeable sieves (4 cm and 1 cm meshes were used for separating the crushed wood chips).

From the 1-4 cm fraction 50 kg of wood chips was transported to Georg August University of Göttingen in Germany where three models of particleboard, bonded with different adhesives were manufactured.

At the Georg August University, the physical and mechanical properties of the produced models were tested, as well as the release of formaldehyde from the models produced with different adhesives. The laboratory work was conducted by the research team led by prof Roffael Edmone, together with prof Hameed.

An estimation of the possible accumulation of organic carbon (“carbon sink”) and the decrease in emissions of greenhouse gases that could be achieved if the Swedish wood waste was available for use in the particleboard industry has been made by prof Torleif Bramryd, University of Lund.

Characterizing of wood waste from NSR

The annual quantity of wood waste received at NSR recycling plant in Helsingborg is around 20 000 tons.

The wood waste includes discarded furniture, packaging material, pallets made of massive wood or wood- based panels, particleboard, fiberboard and other wood based building and construction residues.

In addition to this also 15 000 - 20 000 tons of garden waste, residues from silviculture treatment and tree trimmings are received at the facility (Figure 3).

Figure 1. Crushed wood waste at NSR

Figure 2. Discarded furniture, packaging and pallets received as waste at NSR

Figure 3. Wood residues and tree trimmings received at NSR

Characterizing of wood chips, produced from wood waste at NSR

For characterizing of the wood chips produced at NSR from mixed wood waste today, ten randomize samples were taken from different places of the heaps of wood chips and packaged in paper bags 10 kg capacity, which have been tagged with the following letters: A, B, C, D, E, F, G, H, I, J (Figure 4Figure 4. Randomize samples taken from the heaps of wood chips).

Three randomize samples were taken from each paper bag after drying wood chips in it under the sun and placed in plastic sacks capacity of 1 kg, which were tagged: A1, A2, A3 etc. (Figure 5). Each sample was sorted to the following components: Chips of massive wood **(a)**, wood chips of manufactured wood (particleboards or other wood-based panels) **(b)** and fines and other impurities **(c)** (Figure 6).

Figure 4. Randomize samples taken from the heaps of wood chips at NSR

Figure 5. Three randomize samples were taken from each paper bag.

Figure 6. The sample's components: Wood chips of massive wood, wood chips of manufactured wood (particleboards or other wood based panels), and fines and other impurities

Figure 7 shows the homogeneity of the wood chips samples components, where the chips of massive wood constitute the major part of the samples 76 % while the wood chips of manufactured wood (particleboards or fiberboards) and fines and other impurities constitute 19 % and 5 % respectively. This mixture of wood chips is unfit for the manufacture of particleboards. So it must be separated into chips of massive wood and chips of manufactured wood (particleboards or other wood based panels) in order to get homogeneous chips of massive wood as a raw material for manufacturing models of particleboards. Fines and other impurities must be separated through screening.

A wood recycling unit fit for producing raw material for the particleboard industry should be equipped with a chipper (grinder) and sieves with different meshes (screens analysis system), stone trap as well as with a magnetic system (metal detector) for separating metals.

Thus, this wood recycling system can contribute to the development of commercial methods for recycling of wood wastes as well as increasing the efficiency of wood wastes recycling.

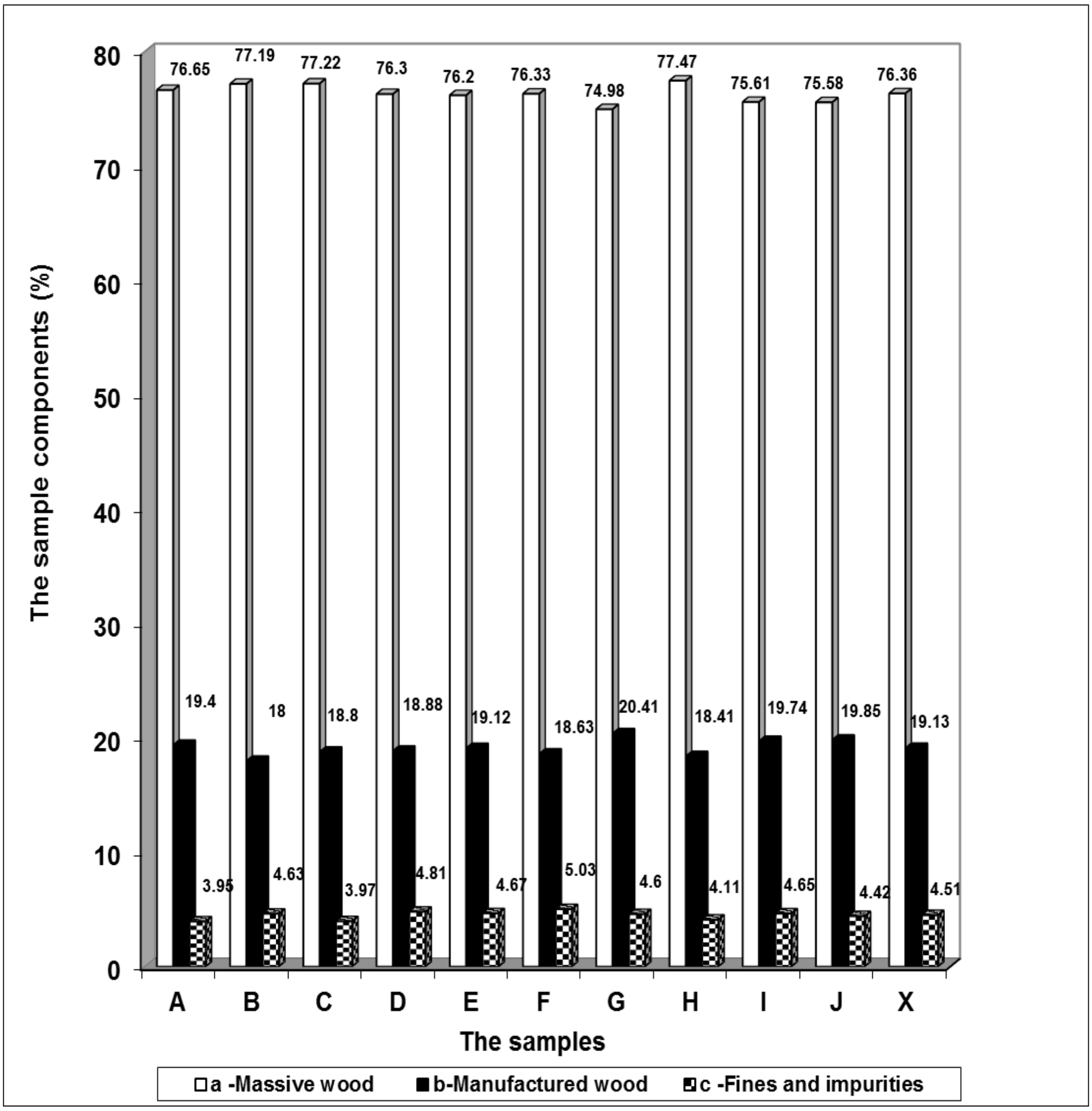

Figure 7. The components of wood chips samples, taken from different places of the heaps of wood chips at NSR

Therefore, from the wood waste should be sorted in appropriate types when received and chipped or crushed (grinded) separately, in order to get homogeneous particles of massive wood and particles of manufactured wood (particleboards) as separate raw materials for the particleboard industry.

Wood waste from NSR can preferably be pre-processed by using the wood processing machinery at NSR and sent to particleboards plants for final preparation.

Preparation and characterizing of wood chips suitable for particleboard manufacturing.

For producing wood chips as raw material for the particleboards in this pilot-project, we focused on clean unpainted wood wastes (discarded furniture, packaging and pallets made of massive wood).

Figure 8. Unpainted wood waste, before and after crushing

A pile of wood waste was selected and approximately 18 tons was crushed three times by using crusher CBI Magnum Force 6400 equipped with magnetic band (Figure 9).

Figure 9. A CBI Magnum Force 6400 was used for crushing the wood waste (three times)

With the magnetic band 160 kg of metal pieces, nails, screws etc were separated from the produced wood chips.

Figure 10. The separated metals, nails and screws.

The produced particles were screened using a drum-sift; Doppstadt SM-518 (Figure 11), equipped with rotary changeable sieves with different meshes (4 cm and 1 cm), Figure 12.

Figure 11 Drum-sift, Doppstadt SM-518

Figure 12 Meshes, 40 mm and 10 mm to Doppstadt drum sift

The amount of wood particles retained on 4-mesh sieve was 2.28 tons (Fraction I) and the amount of wood particles passed through 4-mesh sieve and retained on 1-mesh sieve was 12.02 tons (Fraction II) and the amount of wood particles passed through 1-mesh sieve was 3.57 tons (Fraction III). See **Table 2.**

Table 2 Distribution of particles after drum sifting of crushed wood waste

Particle sieze	**tons**	**%**	
>40 mm	2,28	12,7	Fraction I
10-40 mm	12,02	67,3	Fraction II
<10 mm	3,57	20,0	Fraction III
Total	**17,87**	**100**	

The three fractions were characterized by taking three randomized samples from each fraction, which placed in plastic bags capacity of 1 kg, and tagged: FI, FII and FIII (Figure 9). Three handfuls of wood particles were taken from the samples of each fraction to measure the dimensions and slenderness ratio of the particles (Nasser, 2012), see Figure 14.

Dimensions and slenderness ratio of particles are given in Table 3. It can be noted from Table 2, that fraction I consists of oversize wood particles, which must be re-crushed, on contrary the fraction III consists of small wood particles fines and other impurities, which should be separated by using 0.5-mesh sieve to get fraction can be used for the surface layers of three layers particleboards.

However, the fraction II was the best and fits for manufacturing of particleboards. Therefore, 50 kg of wood particles were taken from fraction II and placed in 2 large bags were shipped to the Georg- August University of Göttingen in Germany as raw material for manufacturing three models of particleboard.

The amount of stones and impurities, that was separated from the original sample (Fraction II) to get 50 kg of wood particles was 2.54 kg (2 kg stones and 0.54 kg impurities) [4.83%], which can be reduced, if a 1.5 cm mesh sieve is used instead of 1 cm mesh sieve. It was also noted that a part of the stones in the sample came from the ground during the loading process to feed the machines with the wood material.

Nevertheless, we conclude that, the efficiency of NSR machinery to get clean wood particles is good but that the process could be optimized by presorting of incoming wood waste and avoiding that the crushed wood chips are mixed with stones and gravel from the ground.

Figure 13. Three randomized samples from each wood fraction.

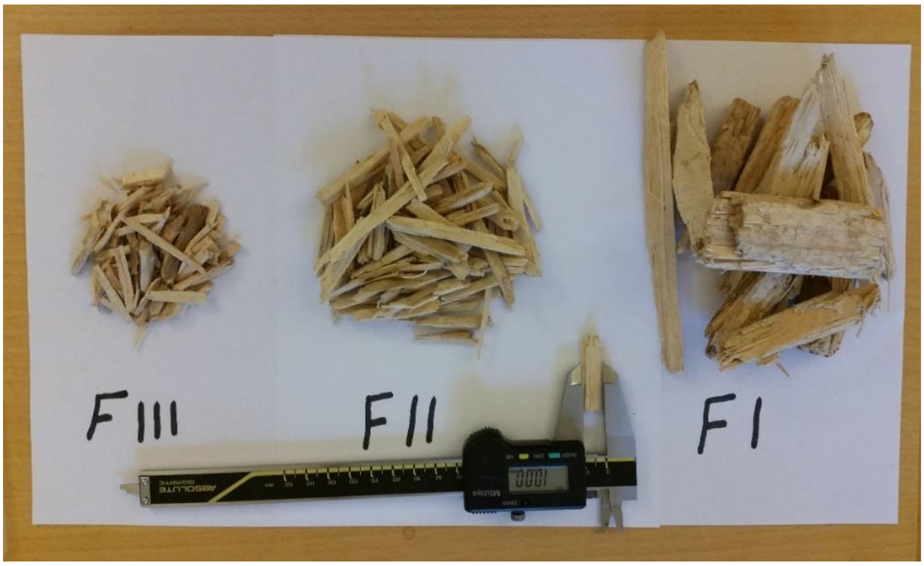

Figure 14. Handful of wood particle taken from the samples of each fraction.

Table 3. Dimensions and slenderness ratio (L/W) of the wood particles sorted by using 1- and 4-cm mesh sieves.

Fraction	N*	Length (cm)	Width (cm)	L/W	Thickness (mm)	Evaluation
I (>4 cm)	95	9.01	2.61	3.45	> 10	Oversize wood particles, which must be re-crushed
II (<4>1 cm)	155	4.31	0.65	6.63	2.06	It fits for manufacturing of one-layer particleboards.
III (<1 cm)	206	2.01	0.41	4.90	1.40	Small wood particles can be separated from the fines and impurities by using 0.5-mesh sieve to get fraction, which fits for the core layer of three layers particleboards.

N* is the number of the measured particles.

Manufacturing three models of particleboard from NSR wood wastes

Raw Materials

44.7 kg of wood particles (fraction II) produced from clean unpainted wood wastes (discarded furniture, packaging and pallets made of massive wood) was used as raw material to manufacture the following three models of particleboard:

a. Three-layer Tannin Formaldehyde resin (TF-resin) bonded particleboard.

b. Three-layer Polymeric Diphenylmethane-diisocyanate (PMDI) bonded particleboard.

c. Three-layer Combination of TF-resin,/PMDI-bonded particleboard.

The information about the TF-resin, PMDI and TF, PMDI adhesives used is listed in Table 4.

Table 4. Information about the TF-resin, PMDI and TF, PMDI adhesives

Adhesives	Information
TF-resin	Quebracho Tannin from Industria Argentina Unitan S.A.I.C.A company (powder)
PMDI	EM 4352 HUNTSMAN company
TF,PMDI	Quebracho Tannin powder, EM 4352 (combination 25:75).

Preparation of Particles

44.7 kg of wood particles were chipped by using a knife ring flaker; Modul System ø 60 cm (Figure 15). The moisture content of the produced wood particles was 13.8% (four replicates by using Sartorius MA). The produced particles were screened using a Tumbler-sift machine; ALLGAIER (Figure 16), which is equipped with changeable sieves with different meshes 4 mm x 4 mm and 3.15 mm x 1 mm (CL), 3 mm x 1 mm and 0.4 mm x 0.4 mm (SL). The wood particles retained on 4 mm -mesh sieve were re-chipped. The wood particles passed through 4 mm-mesh sieve and retained on 3.15 mm-mesh sieve were used for core layer (22 kg, 12% MC) [Figure 17]. The wood particles passed through 3 mm-mesh sieve and retained on 0.4 mm-mesh sieve were used for surface layers (15 kg, 12.3% MC) [Figure 18]. The wood particles passed through 0.4 mm-mesh sieve were removed (fines and wood dust). The wood particles fractions of the core layer as well as surface layers were characterized by using a Laboratory screen analysis system; Retsch AS 400 (250 rpm for 5 min) and listed in Table 5.

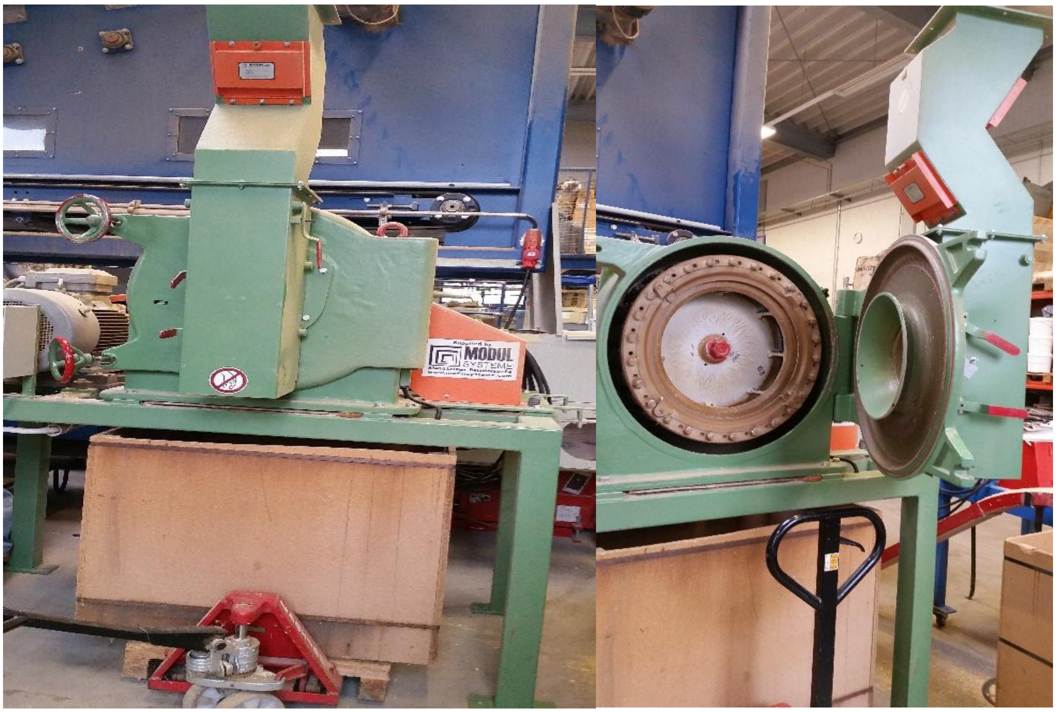

Figure 15. A knife ring flaker; Modul System ø 60 cm.

Figure 16. A Laboratory Tumbler-sift machine; ALLGAIER.

Figure 17. Wood fraction for core layer.

Figure 18. Wood fraction for surface layers.

Table 5. Screen analysis of the wood particles used in the core layer and the surface layers.

Core layer		Surface layers	
Fraction (Sieve mesh size)	Mass-%	Fraction (Sieve mesh size)	Mass-%
>4mm	1.5	>1mm and ≤ 2mm	20.4
>3.15mm and ≤4mm	11.0	>0.4mm and ≤ 1mm	65.2
>1mm and ≤ 3.15mm	83.5	>0.2mm and ≤ 0.4mm	13.3
≤ 1.0mm	4	≤ 0.2mm	1.1
Total	100		100

Board manufacturing

Medium density three layers particleboards were fabricated by using different adhesives (TF-resin, PMDI and combination of TF, PMDI). Wood particles of SL and CL were oven dried at 75°C using a drying cabinet to reach about 2% moisture content (Figure 19). Constant weight of particles was weighted to obtain the targeted final bulk density of 0.62 g /cm^3 and thickness of 19 cm.

The wood particles were mixed (blended) with different adhesives (TF-resin, PMDI and TF/ PMDI) using a Laboratory-type blender (Figure 20). Immediately, the mixed particles were hand-felted into a frame 75 x 50 cm on metal plate and pre-pressed by hand. Thereafter, the frame was removed (Figure 21) and the mat was hot pressed using a Laboratory press, model Siempelkamp (Figure 22). The pressed particleboard was then trimmed (700 mm x 450 mm) to avoid edge effects (Figure 23) and sanded (grain size 60) to a board thickness of 18mm by using a wide belt sanding machine (Type FW 950 C/Co. Felder KG, Hall in Tirol/Austria) (Figure 24). The boards were then conditioned for 4 weeks at 65±5% relative humidity and 20°C to reach equilibrium moisture content, cut into various sizes for testing. Three boards were manufactured for each wood models (9 boards in total) [Figure 25]. The manufacturing conditions of the three models of particleboard are listed in Table 6.

Figure 19. Drying of the wood particles at 75°C.

Figure 20. Laboratory-type blender.

Figure 21. Forming the board, the mixed particles were hand-felted into a frame 70 x 45 cm on metal plate and pre-pressed by hands.

Figure 22. The mat was hot pressed using Laboratory press, Siempelkamp.

Figure 23. Trimming the manufactured models of particleboard.

Figure 24. Sanding the manufactured models of particleboard.

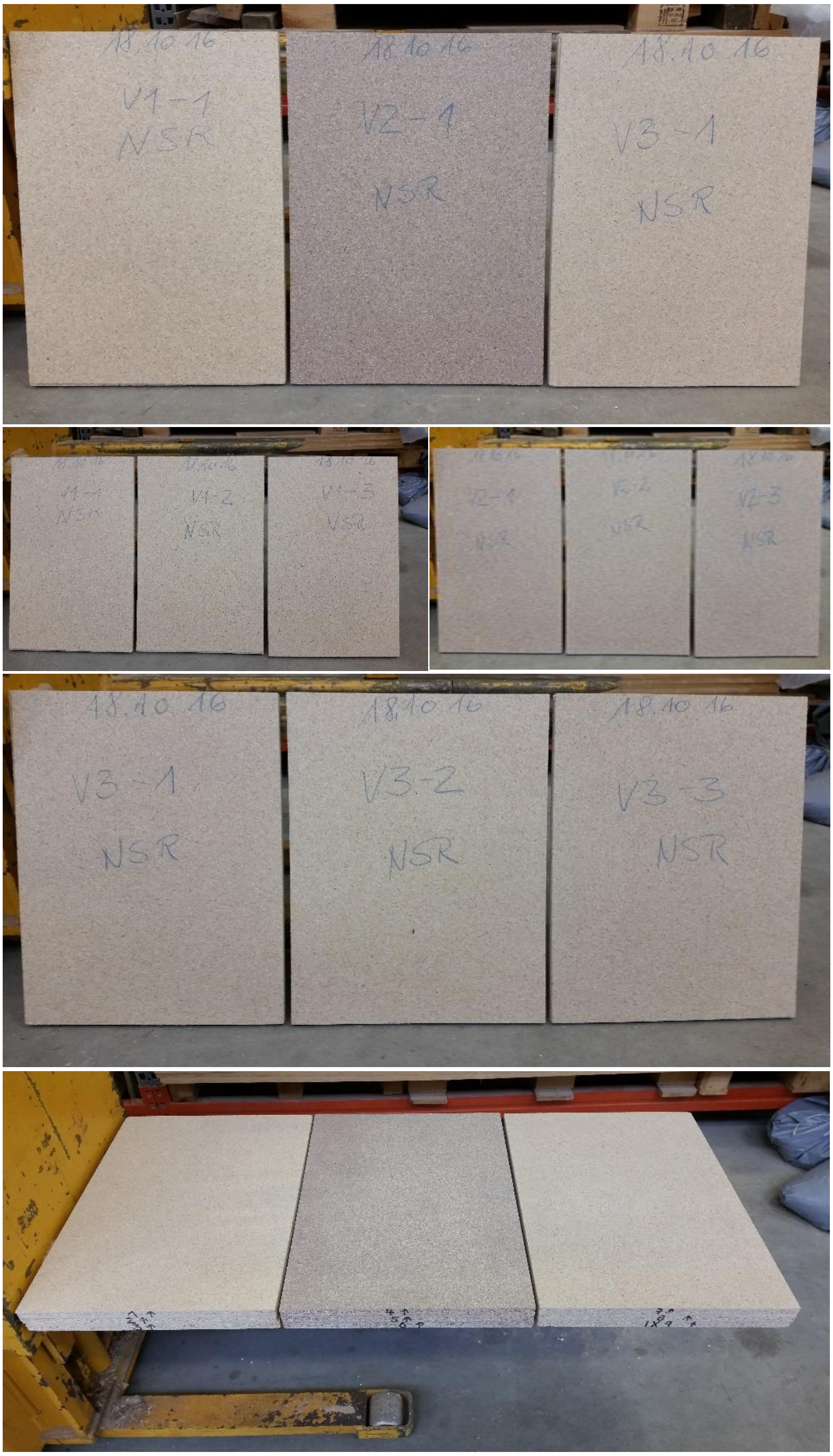

Figure 25. The manufactured models of particleboard.

Table 6. The manufacturing conditions of the three models of particleboards from wood wastes

Model No.	1	2	3
Resin type	PMDI	Tannin-Formaldehyde (TF)	PMDI / TF (Mixture)
Quality of particles	massive wood waste from NSR	massive wood waste from NSR	massive wood waste from NSR
Number boards per variant	3	3	3
Layers	3	3	3
Mass percentage Surface Layer (%)	40	40	40
Mass percentage Core Layer (%)	60	60	60
Particle size Surface Layer (mm)	> 0,2 ≤1,0	> 0,2 ≤1,0	> 0,2 ≤1,0
Particle size Core Layer (mm)	> 1,0 ≤4,0	> 1,0 ≤4,0	> 1,0 ≤4,0
Target density (kg/m³)	620	620	620
Thickness (mm) (sanded)	18	18	18
Board format (trimmed, mm)	700 x 450	700 x 450	700 x 450
Press temperature (°C)	200	190	200
Press time factor (s/mm)	8	15	10
Moisture content particles before pressing %	9-10 %	12-14 %	10 %
Surface layer - Type of resin	PMDI	Tannin-Formaldehyde (TF)	PMDI + TF = 75% : 25%
Surface layer - Resin content (%solid content based on oven-dry weight of the wood particles)	4%	11%	4% PMDI + TF = 3% : 1%[1]
Core layer - Type of resin	PMDI	Tannin-Formaldehyde	PMDI + TF = 75% : 25%
Core layer - Resin content (% solids resin / oven-dry particles)	3%	9%	3% PMDI+TF = 2,25% : 0,75%[1]
Sizing Agent (% solids / oven-dry particles) Sasol Hydro Wax 730 batch 63845	0,5%	0,5%	0,5%

[1] Ratio PMDI: TF-resin based on SL/CL resin content of PB Model No. 1 (PMDI-bonded PB)

Physical properties; Moisture Content, Density, Water absorption and Thickness swelling.

Moisture content, density, water absorption and thickness swelling were determined according to European Norms (EN: 2010) (DIN, 1999) [Moisture Content (EN 322), Density (EN 323), Water absorption (EN 52351), and Thickness swelling (EN 317)]. For density, water absorption and thickness swell-test, the particleboard was cut into 5 cm x 5 cm squares (The test specimens Figure 26) and soaked (immersed) in water at room temperature for 2 and 24 h (Figure 27).

Specimen's thickness and weight were measured before soaking and after 2 and 24 h of water immersion to determine the short-term and long-term water absorption and thickness increase (Figure 28). The results of water absorption and thickness swelling after 2 and 24 h were expressed as a percentage of the original state.

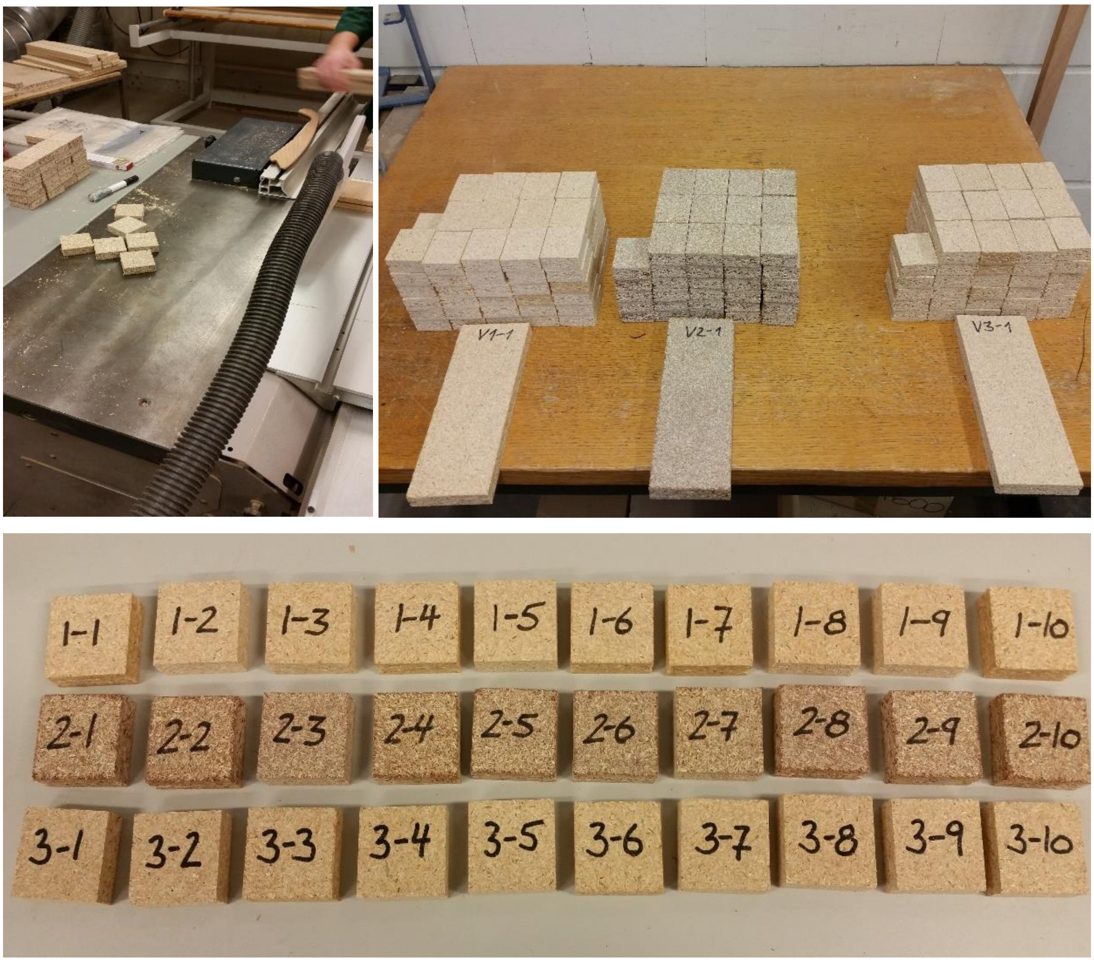

Figure 26. The specimens for density, water absorption and thickness swell- test.

Figure 27. Soaking specimens in water at room temperature for 2 and 24 h.

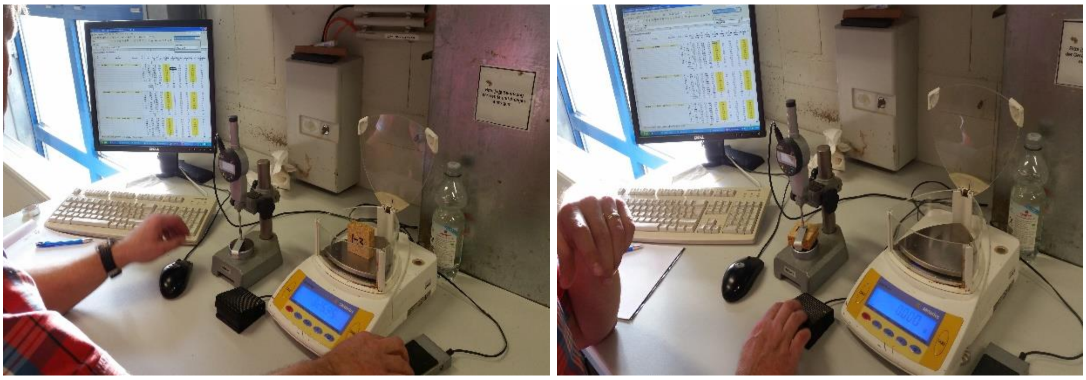

Figure 28. Specimen's thickness and weight were measured before soaking and after 2 and 24 h of water immersion to determine the water absorption and thickness swelling.

Mechanical properties; Static bending strength test and internal bond.

Particleboards of the manufactured Models were cut into 5 cm x 41 cm (thickness x 20+5) rectangular sections for determining static bending strength (Three-point static bending perpendicular to board surfaces) [Figure 29], and 5 cm x 5 cm squares for internal bond (IB) strength measurements (Figure 30). To determinate the internal bond, a 5 cm square sample of board is glued between two wood blocks. The blocks are then pulled apart and the load to failure is recorded **(**Figure 31**)**. Mechanical properties were determined according to the European standards method (EN: 2010) [Static bending strength test (EN 310) and internal bond (EN 319) using a Zwick/Roell 10 testing machine. The crosshead speeds were 5 mm/min for the static bending and IB tests. Modulus of elasticity (MOE) [Figure 32] and internal bond strength (IB) were recorded. After static bending test, the specimens of moisture content were cut from the ends of the bending specimens, where the moisture content determined according to the European Norms EN 322 (EN: 2010).

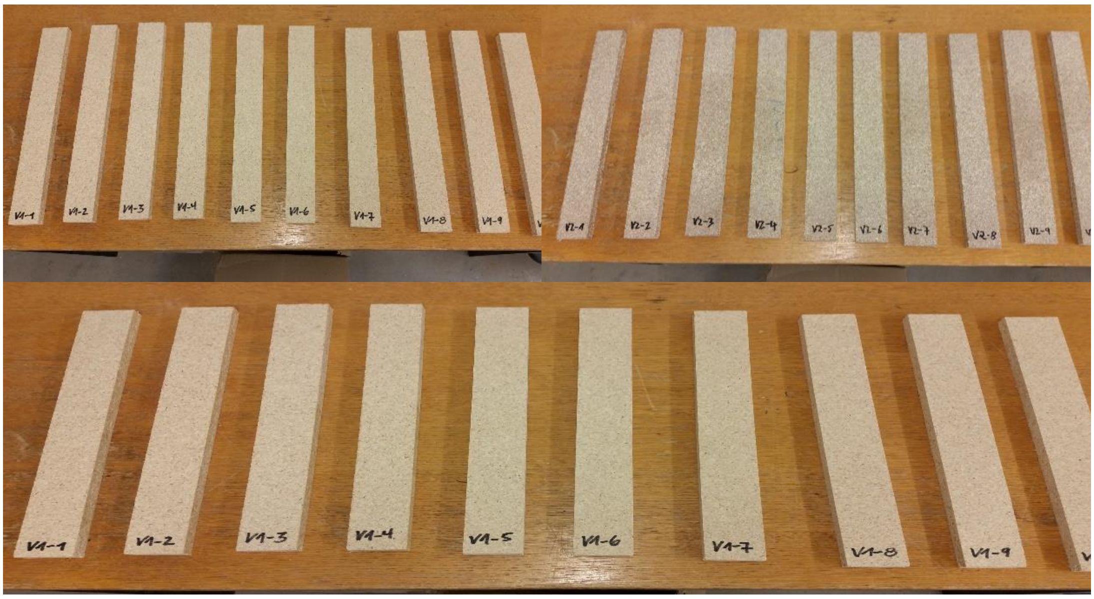

Figure 29. Samples for determining static bending strength (EN 310).

Figure 30. Samples for determination of internal bond (IB) strength (EN 319).

Figure 31. Determination of internal bond (IB) strength (EN 319).

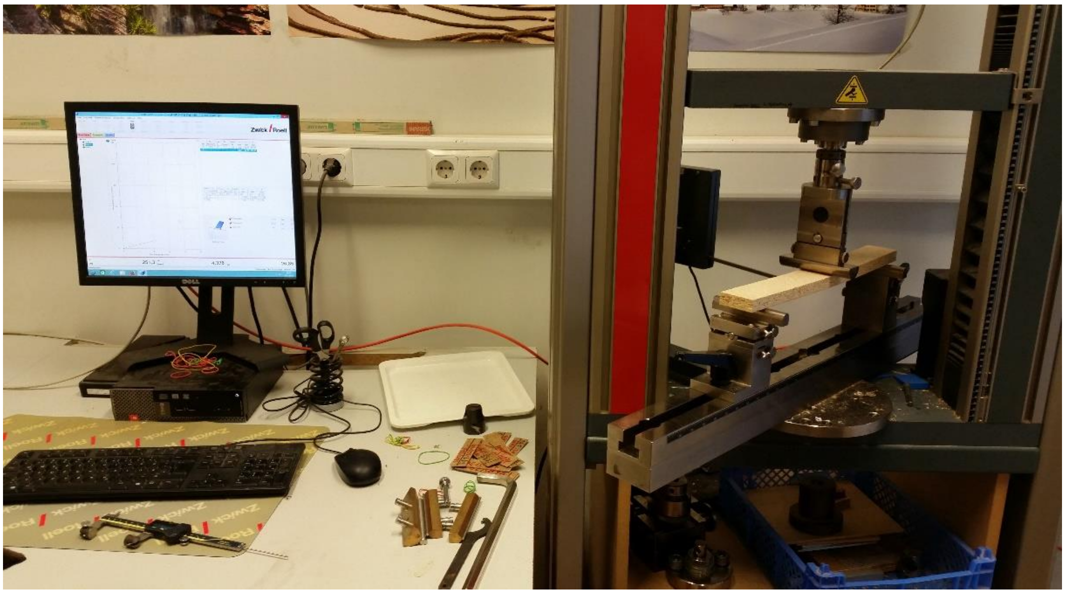

Figure 32. Determination of the static bending strength (EN 310).

Determination of the Formaldehyde Release

2.5 cm square samples were cut from the manufactured particleboards models (Figure 33) for the determination of extractable formaldehyde, according to the perforator method, EN 120, Figure 34 and formaldehyde release, according to WKI-flask-method, EN 717-3 (3h and 24h, Figure 35 of the manufactured PB models. Moreover, also the moisture content of the test samples was determined after conditioning.

Figure 33. Samples for the determination of extractable formaldehyde and formaldehyde release of the manufactured PB models.

Figure 34. Determination of extractable formaldehyde acc. to perforator method, EN 120 from the manufactured PB models.

Figure 35. Determination of formaldehyde release acc. To WKI-flask- method, EN717-3 from the manufactured PB models.

Results and Discussion

Mechanical Properties:

The average values and variation coefficient of internal bond strength, static bending strength and modulus of elasticity of the three manufactured models of particleboard are given in Table 7. It can be noted from Table 7 that the three-layer combination of TF-resin/PMDI-bonded particleboard (Model No. 3) had the highest internal bond strength value (IB) [0.53 N/mm²] followed by three-layer PMDI-bonded particleboard (Model No. 1) [0.49 N/mm²]. The lowest internal bond strength value (IB) [0.27 N/mm²] was obtained with three-layer TF-bonded particleboard (Model No. 2). The IB values of the particleboards: model 1 and 3, complied with the specifications of European standard EN 312 (2010). They fulfilled the requirement for interior fitments (including furniture) for use in dry conditions (Type P2) as well as the IKEA Industry Hultsfred AB requirements for 18 mm standard board for a specific use [≥ 0.34 N/mm²].

Furthermore, the IB strength of the particleboards: model 1 and 3 exceeded the maximum maximum standard specifications (0.35 N/mm²) set by EN 312 (2010), they are therefore the therefore the superior models. Regarding the IB value of model 2, which attained the lowest the lowest value, it is considered acceptable, if we take in consideration the high moisture moisture content of IB test samples after conditioning (9.9%). Regarding to static bending bending strength and modulus of elasticity (MOE) values, it is clear from

Table 7 that three-layer PMDI-bonded particleboard (Model No. 1) attained the highest static bending strength and modulus of elasticity (MOE) values [14.7 and 2490 N/mm², respectively] followed by three-layer Combination of TF-resin/PMDI-bonded particleboard (Model No. 3) [13.6 and 2360 N/mm², respectively]. The three-layer TF-bonded particleboard (Model No. 2) attained the lowest values [9.5 and 1940 N/mm², respectively]. The static bending strength and MOE values of the particleboards: model 1 and 3, complied with the specifications of European standard EN 312 (2010). They fulfilled the requirement for interior fitments (including furniture) for use in dry conditions (Type P2) as well as the IKEA Industry Hultsfred AB requirements for 18 mm standard board for a specific use [≥ 9.0 N/mm²]. Moreover, the static bending strength and MOE values of the particleboards: model 1 and 3 were higher than the minimum requirements (1600 N/mm²) specified by EN 312 (2010), they are therefore the superior models. If we take into consideration the moisture content of the samples tested after conditioning, we find that the two models (1 and 3) at the same level and the values of static bending strength and MOE of model 2 are acceptable.

Table 7. The average values of internal bond strength, static bending strength and modulus of elasticity of the three manufactured models of particleboard.

PB Model No.	Resin Type SL/CL	Density of tests samples after conditioning kg/m³	Moisture content of tests samples after conditioning %	Internal bond strength (EN 319) N/mm²	Bending strength (EN 310) N/mm²	Modulus of elasticity in bending (EN 310) N/mm²
1	PMDI	658 (VC 0.5%)	9.2	0.49 (VC 7.8%)	14.7 (VC 9.7%)	2490 (VC 6.5%)
2	TF-resin	656 (VC 1.0%)	9.9	0.27 (VC 9.5%)	9.5 (VC 10.0%)	1940 (VC 4.3%)
3	TF-resin+ PMDI (25:75%)	657 (VC 0.4%)	9.4	0.53 (VC 7.0%)	13.6 (VC 12.9%)	2360 (VC 8.6%)
IKEA Industry Hultsfred AB requirements for 18 mm standard board for a specific use*		620	5-6	≥ 0.34	≥ 9.0	No requirements
Requirements EN 312:2010 P2 >13 to 20 mm		–	5-13	≥ 0.35	≥ 11.0	≥ 1600

* Data delivered by IKEA, Industry Hultsfred AB, Values are arithmetic mean values of n= 10 samples VC = variation of coefficient EN 312:2010 (Type P2) → Boards for interior fitments (including furniture) for use in dry conditions.

Physical Properties

The average values and variation coefficient of thickness swelling (2h and 24h) and water absorption (2h and 24h) of the three manufactured models of particleboard are presented in Table 3. It is apparent from the results in Table 3 that the lowest values of thickness swelling after 2h and 24h, were obtained with three-layer Combination of TF-resin/PMDI-bonded particleboard (Model No. 3) [0.3 and 6.8 %, respectively] followed by three-layer PMDI-bonded particleboard (Model No. 1) [1.6 and 8.3 %, respectively]. The highest values of thickness swelling after 2h and 24h recorded with three-layer TF-bonded particleboard (Model No. 2) [9.5 and 38.9 %, respectively].

The values of thickness swelling after 2h and 24h of models 1 and 3 as well as model 2 after 2h fulfilled the IKEA Industry Hultsfred AB requirements for 18 mm standard board for a specific use* [≤ 10% and 20-25 %, respectively], except for the higher value of thickness swelling after 24h of models 2 [38.9%], which may be attributed to the high moisture content of thickness swelling test samples of model 2 after conditioning (9.9%). However, the three-layers Combination of TF-resin/PMDI-bonded particleboard (Model No. 3) is superior.

Regarding to water absorption (2h and 24h) values, it can be seen from Table 8 that, the lowest values of water absorption after 2h and, were obtained with three-layers PMDI-bonded particleboard (Model No. 1) [8.8 %] followed by three-layer Combination of TF-resin/PMDI-bonded particleboard (Model No. 3) [9.3%], while, the model no. 3 attained the lowest values of water absorption after 24h [27.7%] followed by models no. 1 [29.4]. The highest values of water absorption after 2h and 24h was recorded with three-layer TF-bonded particleboard (Model No. 2) [35.7 and 103.7%, respectively].

There are no European standards for neither thickness swelling (2h and 24h) and water absorption (2h and 24h) of particleboard listed in EN 312 (2010). However, the values of thickness swelling and water absorption obtained in the current study were lower than the values reported for the three layers' particleboards produced from wood residues (Zhongli *et. al.*, 2006; Nazerian *et. al*, 2011; Nasser, 2012).

Table 8. The average values of thickness swelling (2h and 24h), water absorption (2h and 24h) of the three manufactured models of particleboard.

PB Model No.	Resin Type SL/CL	Density of tests samples after conditioning kg/m³	Moisture content of tests samples after conditioning %	Thickness swelling (EN 317)		Water absorption (DIN 52351)	
				2 h (%)	24 h (%)	2 h (%)	24 h (%)
1	PMDI	644 (VC 0.7%)	9.2	1.6 (VC 19.7%)	8.3 (VC 8.7%)	8.8 (VC 5.5%)	29.4 (VC 4.8%)
2	TF-resin	643 (VC 0.5%)	9.9	9.5 (VC 28.0%)	38.9 (VC 5.6%)	35.7 (VC 19.2%)	103.7 (VC 3.2%)
3	TF-resin+ PMDI (25:75%)	643 (VC 0.8%)	9.4	0.3 (VC 79.9%)	6.8 (VC11.8 %)	9.3 (VC 4.5%)	27.7 (VC 4.2%)
IKEA Industry Hultsfred AB requirements for 18 mm standard board for a specific use*		620	5-6	≤ 10%	20-25%	No require-ments	No require-ments
Requirements EN 312:2010 P2 >13 to 20 mm		_	5-13	No require-ments	No require-ments	No require-ments	No require-ments

* Data delivered by IKEA, Industry Hultsfred AB, Values are arithmetic mean values of n= 10 samples VC = variation of coefficient EN 312:2010 (Type P2) → Boards for interior fitments (including furniture) for use in dry conditions.

Formaldehyde release and extractable formaldehyde

Table 9 shows the average of extractable formaldehyde and formaldehyde release (3h and 24h) of the manufactured models of particleboards. It is that the lowest value of extractable formaldehyde, was obtained from three-layers PMDI-bonded particleboard (Model No. 1) [0.7 mg/100 g o.d. board] followed by three-layers combination of TF-resin/PMDI-bonded particleboard (Model No. 3) [1.9 mg/100 g o.d. board] The highest value of extractable formaldehyde was recorded with the three-layers TF-bonded particleboard (Model No. 2) [6.7 mg/100 g o.d. board].

The extractable formaldehyde values of the manufactured models of particleboards 1, 2 and 3 complied with the specifications of European standard EN 312 (2010) [≤ 8.0 mg/100 g o.d. board]. They fulfilled the requirement for interior fitments (including furniture) for use in dry conditions (Type P2). The extractable formaldehyde values of model 1 and 3 fulfilled the IKEA Industry Hultsfred AB requirements for 18 mm standard board for a specific use [2.7 mg/100 g o.d. board].

It is clear from the results listed in Table 9 that the lowest values of formaldehyde release after 3h and 24h, were obtained with three-layers PMDI-bonded particleboard (Model No. 1) [2.0 and 11.6 mg/1000 g o.d. board, respectively] followed by three-layer Combination of TF-resin/PMDI-bonded particleboard (Model No. 3) [4.6 and 23.4 mg/1000 g o.d. board, respectively]. The highest values of formaldehyde release after 3h and 24h was recorded with three-layer TF-bonded particleboard (Model No. 2) [17.9 and 100.8 mg/1000 g o.d. board, respectively], that could be attributed to the high moisture content of test samples of model 2 after conditioning (9.9%).

It can be seen from

Table 10, that a significant reduction in the formaldehyde release of the (3h and 24h) of the manufactured models of particleboards occurred as a result of a 20 days storage time under normal room conditions (compare results in Table 9). The lowest values of formaldehyde release after 3h and 24h, were obtained with Model No. 1 (1.1 and 6.7 mg/1000 g o.d. board, respectively) followed by Model No. 3 (2.5 and 17.2 mg/1000 g o.d. board, respectively). The highest values of formaldehyde Release after 3h and 24h, recorded with Model No. 2 (8.1 and 57.3 mg/1000 g o.d. board, respectively).

There are no European standards for formaldehyde release (3h and 24h) according to EN717-3 (WKI-flask- method) listed in EN 312 (2010). However, the values of formaldehyde release (3h and 24h) obtained in the current study were similar or slightly lower than the values reported in other research work related to this topic (Lee *et. al.*, 1994; Rosamah 2003; Essa 2012; Noman *et. al.*, 2014).

Table 9. The average values of extractable formaldehyde and formaldehyde Release (3h and 24h) of the manufactured models of particleboards.

PB Model No.	Resin Type SL/CL	Moisture content of formaldehyde tests samples %	Extractable formaldehyde according to EN 120:1992(perforator method) [mg/100 g o.d. board]		Formaldehyde Release according to EN717-3:1996 (WKI-flask- method) [mg/1000 g o.d. board]	
			A	B (corr. 6.5% M.C.)	3 h	24 h
1	PMDI	9.2	1.1	0.7	2.0	11.6
2	TF-resin	9.9	12.3	6.7	17.9	100.8
3	TF-resin+ PMDI (25:75%)	9.4	3.0	1.9	4.6	23.4
IKEA Industry Hultsfred AB requirements for 18 mm standard board for a specific use*		5-6		2.7	No requirements	No requirements
Requirements EN 312:2010 P2 >13 to 20 mm		5-13		≤ 8.0** (≤ 6.5)***	No requirements	No requirements

* Data delivered by IKEA, Industry Hultsfred AB.
≤ 8.0 mg/100 g o.d. board (maximum value); *≤ 6.5 mg/100 g o.d. board (maximum value) as 6 month rolling average. Formaldehyde tests were carried out as double determinations.
EN 312:2010 (Type P2) → Boards for interior fitments (including furniture) for use in dry conditions.

Table 10. Formaldehyde release (acc. EN 717-3 (3h and 24h) of the 3 different PB models 20 days after the first formaldehyde testing (compare results in table 4). The formaldehyde test samples were conditioned during the 20 days storage time under normal room conditions.

PB Model No.	Resin Type SL/CL	Moisture content of formaldehyde tests samples %	Formaldehyde Release according to EN717-3:1996 (WKI-flask- method) [mg/1000 g o.d. board]	
			3 h	24 h
1	PMDI	7.4	1.1	6.7
2	TF-resin	7.9	8.1	57.3
3	TF-resin+ PMDI (25:75%)	7.4	2.5	17.2
IKEA Industry Hultsfred AB requirements for 18 mm standard board for a specific use*		5-6	No requirements	No requirements
Requirements EN		5-13	No requirements	No requirements

312:2010 P2 >13 to 20 mm			

* Data delivered by IKEA, Industry Hultsfred AB.
EN 312:2010 (Type P2): Boards for interior fitments (including furniture) for use in dry conditions.
Formaldehyde tests were carried out as double determinations

In a technical report, presented in Annex 2, the experimental work performed at Georg-August-University and the results are summarized.

Environmental aspects on improved recovery of wood waste

Background

During the last 150 years the atmospheric CO_2 concentration has increased by almost 100 ppm compared with the pre-industrial period and in 2005 reached a value of approximately 379 ppm. The natural range of carbon dioxide concentrations over the last 650 000 years is about 180-300 ppm, and thus the present values far exceed these values. Over the period 1995-2005 the average growth-rate of the atmospheric carbon dioxide concentrations was about 1,9 ppm per year on an average. (IPCC, 2007).

The natural CO_2 balancing processes are insufficient to compensate for the increasing emissions of carbon dioxide. Thus it is of great importance to establish carbon accumulating functions in the urban society. Accumulation of organic carbon in long-lived organic matter in the urban society, like in buildings, libraries, etc is also a process that might delay the release of CO_2 to the atmosphere (Bramryd 1982, 1983). It was estimated that this accumulation in long lived products amounted to about 2.10 x 10^6 g C per capita in industrialized countries and about 0.15 x 10^6 g C per capita in less industrialized countries, resulting in a total sink of carbon in human houses of over 3500 x 10^{12} g organic carbon (Bramryd 1982).

Particle board is such a carbon accumulating product. If woodchips would have been incinerated, most of the organic carbon would have been emitted as CO_2.

Residues from final biological treatment of used particle board material, like compost or bio-residues used in agriculture, horticulture or forestry, where a portion of the organic material is quite resistant to degradation, is good for the carbon balance. The use of such soil improvements especially in sandy soils, or in soils with a high clay content, will increase the humus content and thus also improve biomass productivity, resulting in more accumulation of organic carbon (Bramryd, 2001, 2002).

Life cycle of wood – multiple use and creating eco loops

A possible life cycle of wood products, based on recovery and recycling, could be summarized in the following stages, each with close relation to climate change and environmental and ecological effects.

a) Ecosystem Services of the growing tree already in the forest,

b) Use of wood for furniture production or other products,

c) Recycling of wood waste and production of wood chips to be used in particle boards,

d) Recycling of particleboards 2-3 times (woodchips re-processed from old particleboards into new particleboards)

e) Final use of fragmented particleboards as filter for waste water, process water or landfill leachates rich in nutrients.

f) Composting the material. Use of the compost as fertilizer in forest plantations. As an alternative, non-recyclable board can be used for biogas production.

Environmental benefits from using wood chips derived from waste wood include:

a) Less use of virgin wood material, less pressure on forest management

b) Less energy demands for processing and transportation of timber, etc. It also promotes waste reduction, recycling and a circular economy.

c) When the fibre board material no longer can be re-processed to new fibre board, it can be used as a filter material for local treatment of e.g. leachates or other waste water fractions with a high nutrient content. The used wood chips, mixed with nutrients after being used as filter, can be used for biogas production through fermentation for compost production.

d) The fermentation residues or compost can be used as a non-fossil and low energy demanding soil improvement

e) Organic fertilizers provide addition of humus substances to the soil, and hence increased storage of soil organic matter, in combination with improved water and nutrient holding capacity.

Effects on the CO_2 balance

Increased turn-over time for the wood material provides an increased pool of organic carbon stored in furniture or construction material. Even if the total amount of carbon stored in wooden products at each time probably does not increase, the wood material available for other purposes will be higher, for example to substitute material today produced by fossil raw material.

Especially the possibility to re-use the woodchips in the final stage to something else than fuel, will affect the CO_2 balance and provide a carbon sink. Such a final use of the wood material could be as filter for water purification with a following composting of the material and use as soil improvement. This will bring long-lived organic carbon to the soil and improve the soil capacity as a carbon sink.

The total amount of wood waste in Sweden being used as biofuel is around 1,7 million tons/year (SCB, 2016). The amount of organic carbon in dry wood is approximately 45 % and the mean water content in waste wood can be estimated to around 20 % (considerable variations due to waste origin and storage conditions). If this waste was used as raw material for production of particleboards or other products it would create a carbon sink equal to:

Cm = 0,8 x 0,45 x 1,7 = 0,6 million tons of organic carbon/year.

When/if this amount of carbon is burnt or completely decomposed aerobically the emission of CO2 would be around 2,2 million tons. In comparison the total CO_2-emission in Sweden was 43,4 million tons 2014 (Naturvårdsverket, 2016).

Climatic effects

The process of wood recycling into new products, like particleboard, means that the material is used in a higher level of the “waste hierarchy” decided by the EU and implemented by the Swedish Government. It also contributes to fulfil international climatic goals for decreasing CO_2 emissions and creating more carbon sinks in the environment.

Health aspects

When tannins are used to replace formaldehyde as binding agent in fibre board the risks for allergic symptoms decrease among users.

Sustainability

Tannins are further produced by renewable forest resources and does not contain fossil derived components. In a continued project also other, non-fossil binders such as albumins should be tested.

Conclusions

The conclusions from the pre-study are positive regarding the technical possibilities to use wood waste to produce environmentally friendly particleboards, complying with existing EU-standards. Continued research work is needed to commercialize the results. It is also concluded that recycling of wood waste, as proposed in the pre-study, is very positive regarding environmental och climatic effects.

The conclusions from the study are summarized below:

- Wood waste, delivered to waste management companies like NSR, can be sorted and processed at the recycling facility to a quality suitable for the particleboard industry.
- Ordinary processing machinery, used at the facility (crusher, magnetic separation units and drum sieves) are suitable to produce homogeneous, massive particles/wood chips as a raw material for manufacturing of particleboards.
- The wood waste can preferably be pre-processed at the waste management facility and sent to particleboard production plants for final processing.
- The efficiency of the NSR machinery, primarily intended to produce wood chips for incineration plants, can be further improved and optimized to get clean wood particles, suitable for the particleboard industry.
- Manufacturing of particleboards from wood waste can contribute to a step up in the waste hierarchy from recovery of energy to recovery of material.

- The pre-study indicates possibilities to develop commercial methods for recycling of wood wastes as well as increasing the efficiency of wood waste treatment and reuse at waste management facilities.
- The pre-study has demonstrated for the first time the possibility of manufacturing three-layers combination (25%:75%) of TF-resin and PMDI-bonded particleboards from processed unpainted wood waste (discarded furniture, packaging and pallets made of massive wood).
- The physical- and mechanical properties as well as the level of emissions of extractable formaldehyde from the manufactured models of particleboard complied with the specifications of European standard EN 312:2010 and fulfilled the requirement for interior fitments (including furniture) for use in dry conditions (Type P2).
- The three-layers combination of TF-resin/ PMDI-bonded particleboard showed not only comparable bonding properties to those of pure PMDI-bonded particleboard but also superior properties regarding thickness swelling, water absorption after 24h [27.7%], internal bond strength [0.53 N/mm^2] and amount of extractable formaldehyde [1.9 mg/100 g o.d. board]. Substituting PMDI with Tannin resin as tested in the pre-study could reduce the adhesives cost with 10-15 %.
- It was found that particleboards, produced with a combination of TF-resin and PMDI possessed superior properties to boards made using TF-resin alone.
- The economic/commercial effects of using wood waste from municipal waste management plants as raw material for manufacturing of particleboards and changing adhesives has to be further investigated.
- We conclude that the use of wood waste as raw material for production of particle boards, instead of using it as a biofuel, would contribute to an important accumulation of organic carbon in Sweden.
- The creation of such a “carbon sink” implicates a decrease of carbon dioxide emissions and thereby contributing to mitigate the greenhouse effect and the growing problem of global warming.
- A change in the use of wood waste, from incineration to material recycling (as described in this pre-study) would contribute to the achievement of the national and international climate goals (Convention on climate change, UNFCCC, 1992).
- The results (confirmed by the technical report from Georg- August University of Göttingen) indicate that it is feasible to manufacture various innovative models of particleboards from wood waste as environmentally friendly products.

Next step

The need and possibility of applying new innovative combinations of adhesives (TF, PMDI and others) for particleboard manufacturing has been high-lighted in the pre-study.

Further studies are needed to test and evaluate several combinations of binders (including tannin, albumins and other fossil free binders) and waste materials to find the best technical, environmental and economic solutions for a future, commercial production of sustainable particleboards.

A program for a two years innovation project, as a continuation of the pre-study, has been elaborated by NSR and the University of Lund and an application for financial support (50 %) has be compiled and sent to RE:Source.

Project Communication

During the project contacts have been established with Swedish and German particleboard producing companies, waste management companies, municipalities, construction companies as well as with universities:

- IKEA
    - IKEA Industry Hultsfred AB
    - IKEA Sweden AB
    - IKEA Industry Slovakia
    - IKEA Svenska Försäljnings AB
- Peab AB, Ängelholm
- MTA Bygg och Anläggning AB, Laholm
- SYSAV Utvecklings AB, Malmö
- J G Andersson Söner AB, Linneryd
- Båstad Municipality
- City of Lund
- Elka-Holzwerke GmbH, Morbach, Germany
- Pfleiderer Holzwerkstoffe GmbH, Neumarkt, Germany
- Georg-August University of Göttingen, Germany
- Université Pierre et Marie CURIE

A scientific article, presenting the research results, has been written and sent to the German journal for Wood Technology, “Holtztechnologie”, in January 2017. In March 2017 the article has been reviewed and accepted for publication, see Annex 3.

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Annexes

1. Administrativ bilaga (in Swedish),

2. Technical Report, NSR-1-2016, Georg-August-Universität Göttingen,
3. Scientific Article to “Holtztechnology”, accepted March 2017