**Original Scientific paper**
10.7251/AGRENG2003080T
UDC 636.034.2

# PRE-TREATMENT AND INVESTIGATION OF WHEAT STRAW AND HEMP SHIVES FOR BINDER-LESS FIBREBOARD PRODUCTION

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## ABSTRACT

Wood-based panels (WBP) comprise a considerable part in the output of the European wood industry, GDP, and export. Over 30% of fibreboards and about 50% of other boards used in constructions and carpentry are produced in Europe. Industrially produced WBP contain synthetic adhesives determining mechanical properties and being made from oil are often toxic present health risks. Synthetic adhesives may comprise up to 15 % of the total WBP mass and up to 60 % of the total production costs. Production costs of WBP are important under the circumstances of rising oil prices. Moreover, synthetic bonding agents rather often is a source of emissions of formaldehyde and another problems with advancement of WBP solutions being offered by synthetic adhesives without formaldehyde (polymeric methylene diphenyl di-isocyanate – PMDI), or by natural adhesives from renewables (e.g., tannins or soy flour), or by pre-treatments activating bonding agents contained in the source material. The availability of raw materials for WBP is still another problem under the circumstances of the rate of population growth exceeding the rate of the regeneration of wood resources. Expanding the diversity of raw materials for production of WBP by utilization of agricultural residues containing components like wood is one of the possible solutions. The present study is aimed at development of technology of binder-less fibreboards made of steam-exploded agricultural residues, such as wheat straw (*Triticum aestivum* L.) and industrial hemp (*Cannabis sativa* L.) shives. Some aspects of the study, like differences in chemical composition, thermal properties of raw and pre-treated materials potentially affecting binder-less fibreboard bonding, presented.

**Keywords**: *Wheat straw, Hemp shives, Steam explosion pre-treatment, Binder-less fibreboard.*

## INTRODUCTION

The concept of bio-refinery (Gravitis and Suzuki, 1999) using agricultural residues for value added products meet the European 2020 Strategy where a bio-economy is the key element for innovative product lines based on renewable biological resources, including waste streams or production residues (European Comission, 2012). Industrial hemp (*Cannabis sativa* L.) species approved for cultivation and mainly grown for the long bast fibres widely used in many composites (Shahzad, 2012) becoming the leading crop in Europe, including Latvia (Raymunt, 2020). The hemp woody inner part, called shives, make up to 75% of the stalk mass and have an excellent potential to be used as raw material for value added bio-composites because of its chemical components being similar to wood (Paze *et al.*, 2015). However, almost 2/3 of industrial hemp shives in Europe are used for animal bedding and the rest 1/3 for construction and garden mulch (Romanese, 2019). Some preliminary studies of complex processing of industrial hemp shives have been awarded to products of high added value, such as furfural and self-binding panels (Brazdausks *et al.*, 2015) with acoustic application (Brencis *et al.*, 2015). A significant amount of annual agricultural crops in Latvia takes different cereals from which wheat (*Triticum aestivum* L.) cover about 2/3. After the grain harvesting the straw is the by-product with a limited application. Some surveys demonstrate high potential of wheat straw obtaining fibreboards (Halvarsson, Edlund and Norgren, 2010; Sitz *et al.*, 2017), fuel pellets (Adapa, Tabil and Schoenau, 2011), and bioethanol (Fang, Deng and Zhang, 2011). Also, the wheat straw enhance digestibility in ruminants (Viola *et al.*, 2008).

Steam explosion (SE) is one of efficient pre-treatment technologies subjecting the raw material to hydrothermal modification. In the procedure of auto-hydrolysis the main chemical components of raw material are restructured: the main part of hemicelluloses is destructed, the cellulose is partly depolymerised and a part of lignin – depolymerised and deposited on cellulose fibres separated by decompression (Negro *et al.*, 2003). During the hot-pressing of the pre-treated substance the modified lignin and destruction products of the hemicelluloses and extracts act as bonding agents forming new composite of rather good mechanical properties. SE is a competitive technology for processing diverse raw materials to provide added value of biomass (Zimbardi *et al.*, 2002; Quintana et al. 2009).

Wood-based panels (WBP) are value added composites made of wood particles usually bonded by formaldehyde-containing resins for many construction applications. However, these products emit free formaldehyde, which is classified as carcinogenic (IARC, 2006). Availability of raw materials for WBP is still another problem under the circumstances of the rate of population growth exceeding the rate of the regeneration of wood resources. Expanding diversity of raw materials for production of WBP by utilisation of agricultural residues containing components like wood is one of possible solutions.

The present study demonstrates the potential of wheat straw and hemp shives for binder-less fibreboard production by using the pre-treatment of SE.

## MATERIALS AND METHODS

The most locally cultivated and available retted industrial hemp species of Futura 75 (Kraslava district), Finola and Uso 31 (Jelgava district) were used as hemp shives raw materials. The percentage content of fibre and shives for Futura was 33:62, for Finola and Uso 15:80, respectively. Only hemp shives with a maximum

of 2% of residual fibre content were used for further investigation. Wheat straw was delivered from a farmer in Limbaži district. All raw materials were crushed in a knife mill through a sieve with openings of Ø10 mm removing the fraction of ≤ 0.5 mm because of high ash content (up to 55% in the case of Futura 75).
The crushed raw materials were pre-treated in a steam explosion (SE) device with 0.5 l batch reactor at a temperature range of 200–240°C. The severity factor ($R_0$) combining temperature, *T*, and reaction time, *t* ($R_0 = t*exp[(T-100)/14.75]$) was chosen to express the SE process. The selected experimental design of SE process is shown in Table 1.

Table 1. Experimental design of raw materials for SE process.

| Sample | T, $^0$C | p, bar | t, min | log$R_0$ |
|---|---|---|---|---|
| SE200/1 | 200 | 15 | 1 | 2.94 |
| SE200/3 | 200 | 15 | 3 | 3.42 |
| SE220/2 | 220 | 23 | 2 | 3.83 |
| SE240/1 | 240 | 33 | 1 | 4.12 |
| SE240/3 | 240 | 33 | 3 | 4.60 |

The raw and pre-treated materials were characterized by detected chemical components (NREL/TP-510-42618 and NREL-TP-510-42622) and thermal analysis in terms of differential scanning calorimetry (DSC, heating rate 10°C $min^{-1}$ up to 500°C) and thermogravimetry (TG, heating rate 10°C $min^{-1}$ up to 800°C).
One layer binder-less boards (6 x 150 x 180 mm) were fabricated from crushed (sieve 2 mm) SE materials (fraction 0.05–2 mm, moisture content 5 ± 0.5%) at a constant temperature of 175°C, under maximum pressure of 4 MPa, and pressing rate of 1 min/mm, at the set density level of 900 kg $m^{-3}$. The fabricated boards were cut to the bending test specimen dimensions (50 x 150 mm) and visually evaluated.

## RESULTS AND DISCUSSION

Results of detected chemical components of neat and steam-exploded samples (% of oven dry mass) are shown in Fig. 1. The ash content of used neat hemp shives varies between 2.1% (Finola) and 3.1% (Futura 75), being lower than for neat wheat straw (4.0%). The ash content remains approximately the same after the SE pre-treatment for all used crops except for Futura 75 which ash content significantly increases. The glucan content of neat crops, that is the major portion of cellulose, varies between 39.9% (wheat straw) and 43.5% (Finola). The glucan content of all crops significantly decreases after the pre-treatment; However, the glucan content of Finola and wheat straw increases again at the higher severities of the pre-treatment at SE240/1 and SE240/3 due to the destruction of hemicelluloses. The detected hemicelluloses content (xylan, galactan, arabinan, mannan and acetyl groups) of neat crops varies between 23.2% (Finola) and 26.7% (Uso 31) and rapidly decreases with the lowest severity of the pre-treatment (SE200/1) from 22.5% (wheat straw) to 17.0% (Futura 75) down to 1.8% (Futura 75) – 0.7%

(Finola) at the highest severity of the pre-treatment (SE240/3). The detected lignin content of neat crops varies between 19.4% (wheat straw) and 26.6% (Uso 31) and significantly increases up to 44.0% (Futura 75) – 47.4% (Uso 31) at the highest severity of the pre-treatment.

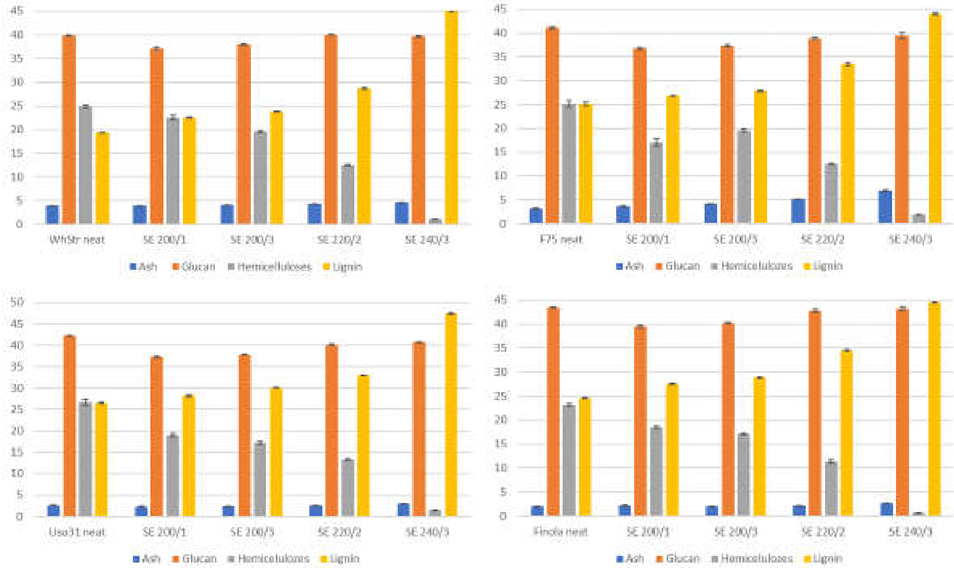


Fig. 1. Chemical components of neat and pre-treated crops (% of oven dry mass).

DSC analysis of all detected raw materials indicated three main exotherms which maximums are at the temperature ranges of 295–315°C, 345–390°C and 420–425°C, and refer to hemicelluloses, cellulose and lignin, respectively (Brys *et al.*, 2016). DSC analysis of pre-treated materials revealed that exotherms maximums at 300–318°C, referring to the degradation of hemicelluloses, remains only for the samples pre-treated at 200°C for 1 min. The exotherms referred to cellulose at 333–390°C and lignin at 390–424°C of all pre-treated samples remains at the same range independent on the pre-treatment conditions (Fig. 2 left).

DSC analysis revealed that softening of Futura 75, Finola, Uso 31, and wheat straw pre-treated at 200°C, 1 min occurs in the temperature ranges of 165–220°C, 180–230°C, 170–215°C, and 170–190°C, respectively. The softening of Futura 75, Finola, Uso 31, and wheat straw pre-treated at 220°C, 2 min occurs in the temperature ranges of 137–140°C, 135–138°C, 163–192°C, and 135–137°C, respectively (Fig. 2 left). The softening of Futura 75, Finola, Uso 31, and wheat straw pre-treated at 240°C, 3 min occurs in the temperature ranges of 130–160°C, 132–140°C, 125–135°C, and 130–150°C, respectively.

Maximum mass losses of all detected raw materials indicated between 336°C and 367°C with sample residue of 15–23% at the end of the process (at 500°C). Maximum mass losses of all detected steam-exploded materials indicated between 302 and 368°C with sample residue of 3–19% at the end of the process (Fig. 2 right).

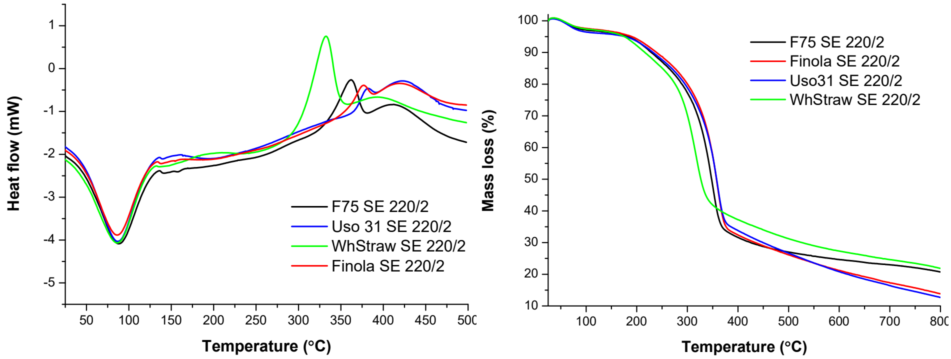


Fig. 2. DSC (left) and TG (right) curves of the crops pre-treated at 220°C, 2 min.

The quality of the boards obtained from the crops pre-treated at 200°C, 1 min and 3 min is poor, because of the particles were not able to be glued strongly and the edges of the boards were not straight after the cutting due to brittleness (Fig. 3, left column). The worst quality of the boards obtained from the samples pre-treated at 200°C demonstrate wheat straw. The boards obtained from the samples pre-treated at 220°C for 2 min and 240 for 1 min have the best quality meeting the minimal technological requirements during the preparation and fabrication of the board (Fig. 3, middle column). The quality of the boards obtained from the samples pre-treated at 240°C for 3 min is quite good (Fig. 3, right column), however, emissions of irritating eyes volatiles were observed during the hot-pressing of the boards.

Fig. 3. Binder-less boards of pre-treated (from above to bottom) hemp shives of Futura 75, Finola, Uso 31, and wheat straw at the 200, 220, and 240°C (from left to right).

## CONCLUSIONS

Steam explosion pre-treatment at 200°C, 1 min resulted to significant decrease in cellulose content for all crops (36.8%–39.5%), however, the increase of pre-treatment temperature up to 240°C resulted to the increase of cellulose of Finola and wheat straw up to the level of neat crop (43.2% and 39.7%, respectively). Hemicelluloses content of all pre-treated crops rapidly decreases from 22.5% (wheat straw) – 17.0% (Futura 75) at the severity of 200°C, 1 min down to 1.8% (Futura 75) – 0.7% (Finola) at the highest severity of 240°C, 3 min. The detected lignin content of neat crops varies between 19.4% (wheat straw) and 26.6% (Uso 31) and significantly increases up to 44.0% (Futura 75) – 47.4% (Uso 31) at the highest severity of the pre-treatment.

The softening feature, suggesting the material pressing temperature, occurs at temperature range of 165-180°C for the crops pre-treated at 200°C, 1 min; 135-163°C for the crops pre-treated at 220°C, 2 min; and 125-132°C for the crops pre-treated at 240°C, 3 min.

The boards obtained from the samples pre-treated at 220°C for 2 min and 240 for 1 min have the best quality meeting the minimal technological requirements during the preparation and fabrication of the board which will be used in the further research.

## ACKNOWLEDGEMENT

This study was supported by the European Regional Development Fund project. Agreement of Research application No. 1.1.1.2/16/I/001, research application No. 1.1.1.2/VIAA/2/18/310 “Investigation of binder-less fibreboards made of steam-exploded wheat straw and hemp shives”.

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