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Chemical and multi-physical characterization of agro-resources' by-product as a possible raw building material

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ABSTRACT

The aim of this paper is to find out the best valuation of agro-resources' by-products as new alternative raw building materials that meet to sustainable development requirement. Five agro-resources are considered: flax, hemp, corn, rape and wheat. In the present work, the chemical characteristics of bio-aggregates are studied by FTIR, Van soest method and Phenol sulfuric method to identify their composition. The investigated physical properties are particle size distribution, density, porosity, water absorption, thermal conductivity and moisture buffer value. The studied materials differ on a chemical and a thermal point of view while they all are excellent hygric regulators. These results suggest that agro-resources can be used as a raw building materials for several types of use: as lightweight aggregates or as binder.

1. Introduction

In recent years, the quantity of agricultural waste has been rising rapidly all over the world and it will continue to increase rapidly. Taking Europe as an example, from agro-resources production in 2015 ("Agricultural production – crops," 2016), the availability of crop residues such as stems or leaves for 12 of the EU's most produced crops can be estimated. The total residue production is calculated by applying two coefficients (field residue production ratio and processing residue production ratio) on the quantity of crop production. There is as many agricultural waste as crop production. Moreover, one-third of the total residue production remains in fields and another third is used for livestock and horticulture. The last third corresponds to available crop residues (Searle and Malins, 2013). On the other hand, estimates on the availability of crop residues in 2020 in Europe, have been produced by Bloomberg New Energy Finance (Bloomberg New Energy Finance, 2010). The comparison of estimated productions with 2015 productions shows that the availability of crop residues will nearly double in 5 years' time (Table 1 and Fig. 1).

As a result, the environmental problems and negative impacts of agricultural waste draw more and more attention. Therefore, there is a need to adopt proper approaches to reduce and reuse agricultural waste. The agricultural residues mainly consist of different straws, such as wheat or corn. A wide range of agricultural waste could potentially be used to produce bio-based materials, aiming at the valorization of the whole biomass and basing on a zero-waste concept, such as biofuels, food and feed ingredients, chemicals and buildings materials (Fava et al., 2015; Hameed, 2014).

Recently, the Isobio project was initiated. This project, supported by the European Union Horizon 2020 program, proposes an innovative strategy to bring bio-based construction materials into the mainstream. A key innovation consists in using bio-based aggregates from a local culture with green binders to produce ecofriendly composites. This project aims to combine existing technologies in order to develop bio-based panels with low embodied energy, low carbon footprint and high hygrothermal efficiency ("ISOBIO – Naturally High Performance Insulation," 2015).

This study aims to value five agro-resources' by-products from flax, hemp, corn, rape and wheat, produced in France, to find out new alternative materials that meet the sustainable development criteria. In this work, the chemical and physical properties of these agricultural by-products, are measured and compared. Composition is studied by FTIR, Van soest method and Phenol sulfuric method to determine the content of cellulose, hemicellulose, lignin and pectin. Particles size distribution is measured by mechanical sieving and by image analysis or by laser granulometry. Bulk density, porosity, water absorption, thermal conductivity and moisture buffer value are investigated. Finally, the conclusions are drawn and the potential uses of the agro-resources' by-product in building materials are highlighted.

Abbreviations: ADF, Acid Detergent Fiber; ADL, Acid Detergent Lignin; ATR, attenuated total reflectance; FTIR, Fourier Transform InfraRed spectroscopy; IRA, initial rate of absorption; MBV, moisture buffer value; NDF, Neutral Detergent Fiber; PSD, particle size distribution; SEM, scanning electron microscopy

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Table 1
Calculation of total agricultural residue production in Europe in 2015 and projected availability of crop residues in 2020.

Biomass	Crop production in 2015 (Mtonnes) ("Agricultural production – crops," 2016)	Field residue production ratio (Searle and Malins, 2013)	Processing residue production ratio (Searle and Malins, 2013)	Total residue production in 2015 (Mtonnes)	Total residue availability in 2015 (Mtonnes)	Total residue availability in 2020 (Mtonnes) (Kretschmer et al., 2012)
Wheat straw	125	0.94	0.24	148	49	74
Barley straw	49	0.94	0.24	58	19	26
Rye residues	4	1.13	0.24	9	3	6
Maize stover (corn)	54	0.80	0.47	68	23	18
Sugar beet residues	76	0.27	0.00	21	7	38
Other agricultural residues	28	1.04	0.24	34	11	56
Sum	**337**	-	-	**338**	**113**	**218**

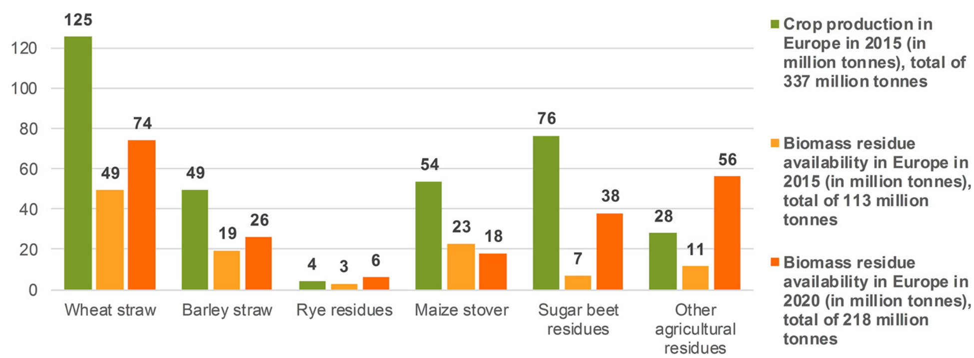

Fig. 1. Crop production and biomass residue availability in Europe in 2015 compared to biomass residue availability in Europe in 2020.

2. Materials and methods

2.1. Materials

This study is performed on five kinds of raw materials with several particle size distributions, collected and processed by CAVAC Company (Vendée, France) in 2015. These raw materials are grown in Vendée.

The bio-based aggregates are processed with an industrial defibering machine by mechanical breaking. In fact, to separate the shiv from the fiber, straw bales are opened, crushed with a hammer mill and sorted into three different categories: fines, fibers and shiv, during the separation process. Only hemp and flax can be changed in fines and fibers. The fines are vacuumed at several process steps. Finally, the shiv are calibrated with different sieving grids (n°7, n°8, n°12 and n°14) using a grader. The uncalibrated shiv go back to hammer mill step (Fig. 2).

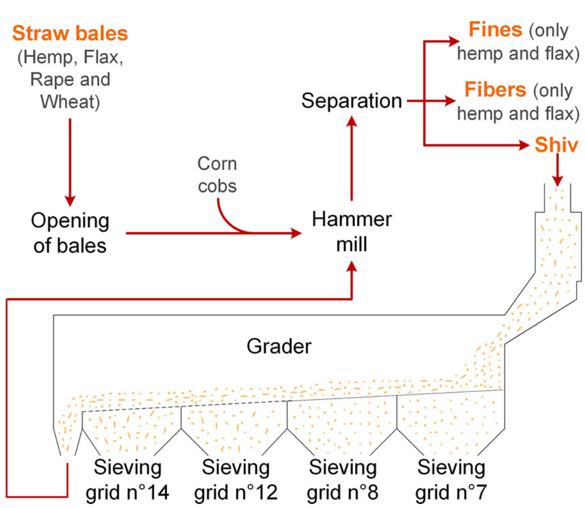

Fig. 2. Bio-based aggregates processing flow-chart.

The 17 selected bio-aggregates are the following (GX = grid number used to grade the aggregates, Fig. 3):

- Hemp shiv (*Cannabis sativa L., Futura 75*): G7, G8, G14 and fines
- Flax shiv (*Linum Usitatissimum L., Angora*): G7, G8, G12, G14 and fines
- Rape straw: G7, G8 and G14
- Wheat straw: G7, G8, G12 and G14
- Corn cobs

The species and variety of rape, wheat and corn are unknown because they are cultivated for their seeds. Therefore, straws or cobs, which are by-products, are mixed without distinctions between variety or species before being sold by the trading industry.

2.2. Methods for microstructure characterization

2.2.1. Scanning electron microscopy (SEM)

SEM experiments are performed in this study to observe the microstructure of the aggregates. Scanning electron microscopy (SEM) is carried out with a JSM 7100F (Jeol) fitted with Schottky field emission and Everhart-Thornley secondary electron detector.

Prior to the analysis, the aggregates are glued with carbon tape and are coated with palladium (layer thickness average 30 nm) to avoid sample charging effect due to the electron beam.

2.3. Methods for chemical characterization

2.3.1. Fourier Transform InfraRed Spectroscopy (FTIR)

FTIR measurements of raw materials are performed using a Perkin Elmer Spectrum with an ATR-FTIR unit. Without advance preparation, the samples are placed on a crystal (diamond). The spectra are obtained with 10 scans in a spectral range of 650 − 4000 cm^{-1} with a resolution of 4 cm^{-1}. The spectra are collected and analyzed using Spectrum software (Perkin Elmer).