New agro-materials with thermal insulation properties

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ABSTRACT

• In a context of awareness of environmental problems, and of limitation of energy spending, it is important to find new solutions for buildings materials, particularly in insulation field. The idea presented here is to use by-products from agriculture as basis for insulation materials.

• Various agricultural by-products such as pith from sunflower, cobs and husks from corn, wheat straw and hemp chaff, were analyzed in term of composition, mechanical structure and thermal properties. The thermal conductivity measurements were performed by hot plate apparatus lambda-Meter EP500. Vegetable matter showing the most interesting characteristics as insulator is then formatted by thermal bonding for using as construction materials. Different vegetable matter granulations and conditions of working are used to achieve various materials density. Thermal performances of these new materials are measured and compared with those of industrial insulating materials.

• Compared to the other analyzed agricultural by-coproducts, sunflower pith presents interesting properties both thermal insulation (37-39mW.m^{-1}K^{-1}) and low density (0.35). Its physical structure allows it to be assembled into agro-material to be used in insulation products. It presents similarity in several properties to expanded polystyrene (i.e., Marechal & Rigal. Ind. Crops Prod. 10: 185, 1999.). The thermal conductivity of the sunflower agro-material (41-43 mW.m^{-1}K^{-1}, density: 60-80 at 25°C) is comparable with that of traditional insulating materials (rock wool: 35mW.m^{-1}K^{-1} at 25°C, expanded polystyrene: 37 mW.m^{-1}K^{-1} at 25°C).

• The good thermal properties and low density of the sunflower pith agro-material designate it as a good candidate for insulation used in construction field. Currently sunflower pith is a by-product which is not valorised and which remains in fields, such an application will require the development of collecting technology.

• Agricultural by-products have the advantage of being derived from renewable resources, being biodegradable and often being produced locally. This permits to have a lower environmental impact than products derived from petrochemicals or mineral products.

Key words: sunflower, pith, insulation**,** agro-materials, biodegradable

INTRODUCTION

Agricultural residues perform an alternative raw material source for buildings materials. In particleboards domain many studies have already been done to replace wood by agricultural residues (kozlowski and helwig, 1998, sunflower stalks: Khristova et al., 1998, Evon et al., 2010, maize husks and cobs: Sampathrajan et al., 1992, wheat straw: Han et al., 1998, rice straw and cotton stalks: Heslop, 1997). But few studies are available on low density material which can have potential application in insulation, packaging or lightweight core materials. One of the only application of the vegetable matters in the domain of low density materials is the use of long fibres for the manufacture of thermal insulations (Flax and hemp fibres: Kymäläinen and Sjöberg, 2008). Specific studies has also been done on low density particuleboard from wheat straw and corn pith (Wang and Sun, 2002), and sunflower pith (Marechal and Rigal, 1999).

The thermal insulation materials used currently in construction are from four types: mineral mat-type insulants, vegetable or animal mat-type insulants, cellular insulants and block-type insulants. The mat-type insulants correspond to volcanic rock wools and glass-wool insulators. They consist of a network of fibers more or less tight. The final properties of materials depend on the organization of fibres. The vegetable or animal mat-type insulants are cork insulation and mat-type insulants containing hemp, flax, sheep wool. The cellular insulants correspond to foams containing bituminous materials (expanded polystyrenes, polyurethane, phenolic foam…). The last family of insulating materials corresponds to the block-type insulants such as cellular concrete and cellular terra cotta.

The objective of this research was to analyze various agricultural by-products in term of composition, mechanical structure and thermal properties and to choose among them the most interesting residue in order to format it for a use as insulation material. Agricultural residues selected for the study are pith from sunflower, cobs, husks and cob from corn, wheat straw and hemp chaff.

MATERIALS AND METHODS

The sunflower stalks are manually harvested in the field and are reduced with hammer mill to maximum 12mm particles size. The pith is separated from the rest of the stalk by pulsed air and is reduced with knife mill to maximum 5mm particules size. EU-Grits-10-14 and EU-Feeds-10 comes from Corn cob. They are provided by the EUROCOB company. EU-Grits-10-14 corresponds to a hard and lignin rich fraction. EU-Feeds-10 corresponds to a weak density fraction. Cornhusks come from a sweet corn manufacture and are reduced with hammer mill to maximum 6mm particules size. Wheat straw is reduced with hammer mill to maximum 5mm particles size.

Cellulose, lignin, and hemicelluloses are quantified according to Van Soest and Wine method (Van Soest and Wine, 1963;1968).

The thermal conductivity measurements are performed by hot plate apparatus lambda-Meter EP500. They are measured at three temperatures 10°C, 25°C and 40°C. For the by-products particles the measurement is realized in polycarbonate boxes of 1mm thickness (dimension: 15cmx15cmx5cm). The particles are placed in the box in a homogeneous way. A correction is made on the measurements of thermal conductivity in order to correct box effects. For the sunflower pith agromaterial the measurements are performed directly on the plate.

The shaping of the sunflower pith agromaterials is realized after absorption of 3g of water per 1g of pith. Wet pith is placed then in a mould and dried at 150°C.

RESULTS

The composition and the density of studied agricultural by-products are presented in table 1. The density varies according to the by-products considered. Sunflower pith has the lowest density. It contains few lignin and important ratio of cellulose. It is constituted from parenchyma tissue. Its structure is from alveolar type (Fig.1.)

Table 1. Composition and density of agricultural coproducts by Van Soest and Wine method.

		density	Ash (%)	Hemicelluloses (%)	Cellulose (%)	Lignins (%)
Sunflower	Sunflower pith	0.018-0.035	17	4-7	45	3-7
Hemp	Hemp chaff	0.11-0.14	2.5	9	52	18
Corn	EU-Grits-10-14	0.33-0.45	1.2	36	47	6.5
	EU-Feeds-10	0.14-0.29	1.6	36	35	5.5
	Cornhusk	0.10-0.14	2.0	37	35	2.7
Wheat straw		0.06-0.13	5.6	31	42	9
Rice hull		0.13-0.16	18	12	36	15

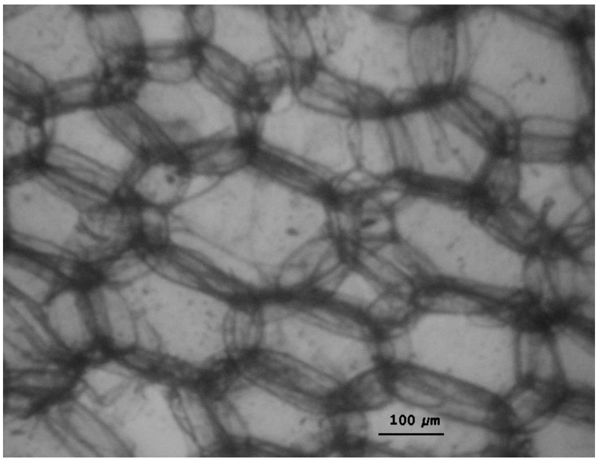

Fig. 1. Alveolar structure of sunflower pith

The measurement realized on particles introduced in the box in a homogeneous way without application of pressure show that the thermal conductivity of agricultural by-products depends on plants, parts of the plant considered, and particles sizes (Table 2).

Table 2. Thermal conductivity measured on particles placed in a homogeneous way in the box

Material		Thermal conductivity (mW.m^{-1}.K^{-1})			Density
		10°C	25°C	40°C	(KG.dm^{-3})
Sunflower	d < 250µm	35.30	37.3	39.20	0.025
	d <1mm	34.95	37.10	39.00	0.022
	1mm < d < 2mm	36.40	38.60	41.10	0.018
	2 mm < d < 5mm	37.10	39.40	42.10	0.018
Corn	EU-FEEDS-10	59.65	62.90	64.10	0.190
	EU-GRITS-10-14	106.45	113.20	121.70	0.514
	cornhusk	48.85	51.95	56.25	0.117
Wheat Straw		42.2	44.90	47.85	0.060
		43.43	46.15	48.90	0.085
		45.70	47.65	49.10	0.130
Rice Hull		51.60	54.83	57.6	0.130
		51.50	54.44	57.38	0.145
		51.65	54.89	57.41	0.160
Hemp Chaff		51.45	54.00	56.65	0.115
		52.80	54.90	57.35	0.135
		52.45	54.70	57.1	0.145

(d: diameter)

Hemp chaff and sunflower pith correspond both at the inner of the plant stalk but they are very different in their structure. Hemp chaff is more lignified. Its structure is like wood. It is denser than sunflower pith. In the box it leads to a higher thermal conductivity than sunflower pith.

The influence of parts of plant on thermal conductivity is illustrated in case of corn. Thermal conductivity is very different for cornhusks and EU-Grits. This is explained by the differences in the physical structure of the two parts of the plant (fibres and hard grains). The organisation in the box is not the same and consequently densities are different. The shape of the particles is important.

The influence of particles size on thermal conductivity is studied in case of sunflower pith. Different particles size doesn't induce a same organisation of particles in the box. An increase of particles sizes generates an increase of empty spaces and by consequence a decrease of the density.

For each plant the thermal conductivity increases proportionally with the density. Best results in term of density and thermal conductivity are obtained with sunflower pith. This by-product is selected to be used as basic raw material for the realization of a new insulation material.

The shaping of the sunflower pith agromaterials according to the described protocol is realized in a metal mould without addition of adhesive (Fig.2). Materials of different density are obtained by using various particle sizes and different application pressures on the mould. The agromaterials obtained are all cohesive and easy to handle (Fig 3).

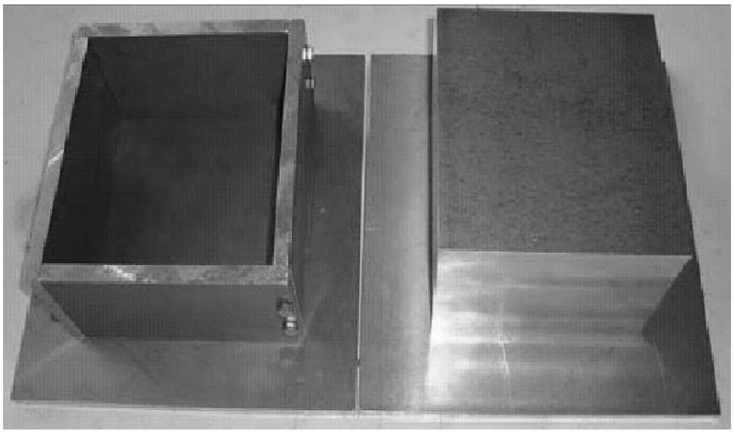

Fig. 2. Mould used to prepare sunflower pith agromaterials

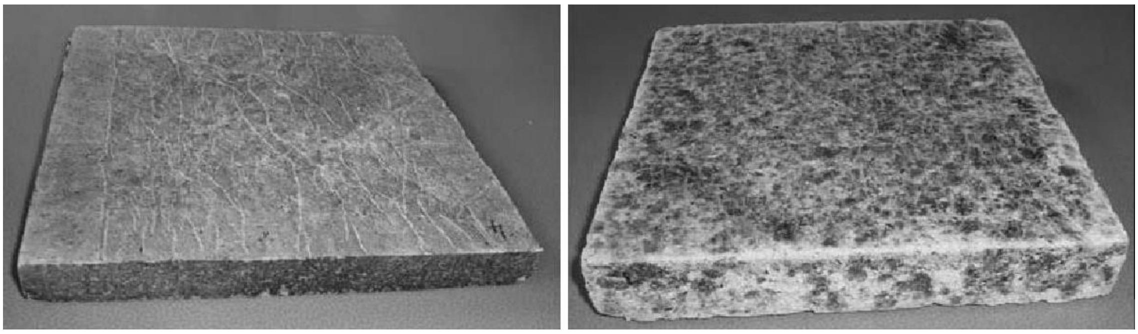

Fig. 3. Sunflower pith agromaterials

The density of the agromaterials obtained is low (table 4). It varies between 0.036 and 0.152. Their thermal conductivity is influenced by it. The lower the density is the lower the thermal conductivity is. The variation is linear and can be translated by an equation (Fig.4).

Table 4. Thermal conductivity of sunflower pith agromaterials

sunflower agro-material	Thermal conductivity ($mW.m^{-1}.K^{-1}$)			Density ($KG.dm^{-3}$)
	10°C	25°C	40°C	
d < 1mm	37.80	38.50	40.35	0.036
d < 1mm	41.90	43.20	44.35	0.080
d < 1mm	48.60	50.15	52.40	0.152
1mm < d <2mm	41.20	43.00	45.10	0.065
2mm < d < 5mm	39.50	41.00	42.40	0.060

(d: diameter)

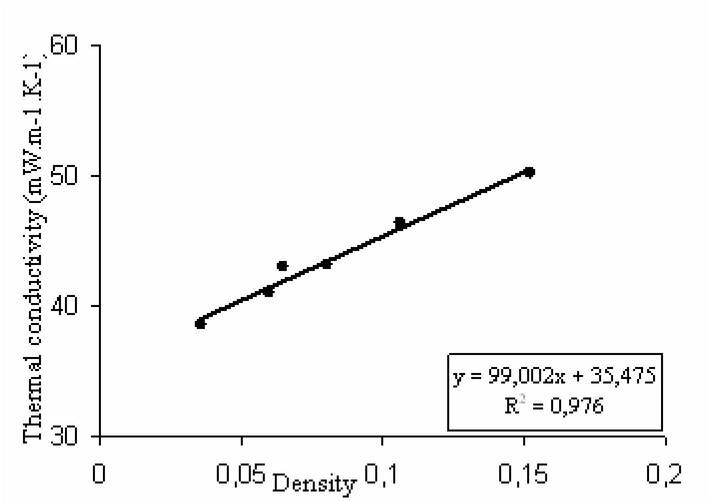

Fig. 4. Thermal conductivity variation according to density

Sunflower pith agromaterial is characterized by one of the weakest density compared with industrial materials used in insulation (Table 5). It has a thermal conductivity near to expanded polystyrenes and not very far from glass-wool and rock wools.

Table 5. Thermal conductivity of industrial materials used in insulation.

material	Thermal conductivity ($mW.m^{-1}.K^{-1}$)			Density
	10°C	25°C	40°C	($KG.dm^{-3}$)
Polyurethane foam	23.45	25.25	27.70	0.030
glass-wool	33.05	35.35	37.95	0.026
rock wools	33.80	35.55	37.35	0.115
expanded polystyrenes	35.60	37.40	39.50	0.050
Sunflower agro-material d < 1mm	37.80	38.50	40.35	0.036

(d: diameter)

DISCUSSION

The study shows that agricultural by-products present interesting properties of thermal conductivity. Their use as insulating materials requires preparation of a final shape easy to handle. The pith of sunflower is a very good candidate for this application type. It has a very weak density. Its thermal conductivity is lowest. No adhesive is necessary to format it. It is enough to humidify and to mould it to obtain a cohesive material easy to handle. The sunflower pith agromaterials have mechanical and thermal properties sufficient to be used as building material in insulation domain.

Compared to most of other agricultural wastes that are often used for animal feed or as a source of fuel, sunflower stalks are not usually collected. They also have the advantage to be available in large quantities.

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