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# Evaluation of Structure Influence on Thermal Conductivity of Thermal Insulating Materials from Renewable Resources

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The development of new thermal insulation materials needs to evaluate properties and structure of raw material, technological factors that make influence on the thermal conductivity of material. One of the most promising raw materials for production of insulation material is straw. The use of natural fibres in insulation is closely linked to the ecological building sector, where selection of materials is based on factors including recyclable, renewable raw materials and low resource production techniques

In current work results of research on structure and thermal conductivity of renewable resources for production thermal insulating materials are presented. Due to the high abundance of renewable resources and a good its structure as raw material for thermal insulation materials barley straw, reeds, cattails and bent grass stalks are used. Macro- and micro structure analysis of these substances is performed. Straw bales of these materials are used for determining thermal conductivity. It was found that the macrostructure has the greatest effect on thermal conductivity of materials. Thermal conductivity of material is determined by the formation of a bale due to the large amount of pores among the stalks of the plant, inside the stalk and inside the stalk wall.

*Keywords*: thermal insulation, renewable resources, straw, structure, thermal conductivity.

## 1. INTRODUCTION

In the last 20 years cellulose based plant fibers have gained importance as raw material for thermal insulations. The use of natural fibres in insulation is closely linked to the ecological building sector, where selection of materials is based on factors including recyclable, renewable raw materials and low resource production techniques [1, 2]. Moreover, thermal insulation from cellulose based plant fibers are used for sound absorption purpose [3 – 6]. One of main requirements for building envelopes is to ensure acoustic comfort, especially in multi-dwelling buildings [7, 8]. Plant fibers for sound absorption are used inside buildings for floors, enclosures, partitions and ceiling insulation. Outdoor following products are used as sound-absorbing walls (fences) to protect against of car noise [9].

Straw is an agricultural by-product, the dry stalks of cereal plants, after the grain and chaff have been removed. Straw makes up about half of the yield of cereal crops such as barley, oats, rice, rye, flax and wheat [10 – 12]. It has many uses, including fuel, livestock bedding and fodder, thatching and basket-making. Straw are used as raw material in the production of thermal insulating fiberboards, reinforced thermoplastic composites and straw bales [13 – 18]. Without agricultural straw as raw material for thermal insulation are used non-cultural plants such as reed, cattail, and nettls. All these plants are used for the production of building materials because they have relatively long stalks [19, 20]. Most of these plants are used barley and wheat straw. For the processing of these straws presses are used, linking the straw into bales. Wide use of straw bales is associated with the the mechanical hay baler, which was invented in the 1850s and was widespread by the 1890s [21, 22].

People have built homes using straw, grass, or reed throughout history. These materials were used because they were reliable and easy to obtain. European houses built of straw or reeds are now over two hundred years old. In the United States, too, people turned to straw houses, particularly after the hay/straw baler entered common usage in the 1890s. Homesteaders in the northwestern Nebraska "Sandhills" area, for example, turned to baled-hay construction, in response to a shortage of trees for lumber. Bale construction was used for homes, farm buildings, churches, schools, offices, and grocery stores [21, 22].

The aim of the present study was to evaluate structure variety of different plants such as barley straw, reed, cattail, bent grass and their use as raw material for production thermal insulating materials.

## 2. EXPERIMENTAL

In tests barley straw, reeds, cattails and bent grass stalks were used. In order to analyze macro (~50 times enlargement) and micro (100 – 250 times enlargement) structure of plants straw, cilindricale specimens $(40 \times 40)$ mm, were prepared. The samples were inspected in a Zeiss EVO-50 EP Scanning Electron Microscope (SEM). Analysis were performed using the variable pressure mode at an accelerating voltage of 20 keV and working distance of 10 mm to 15 mm.

For thermal conductivity tests specimens of $(500 \times 500 \times 100)$ mm were prepared. To get the task form of specimens chipboards on both sides were used.

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Chipboards were connected with metal screws and inside the straw perpendicularly to thermal flow and parallel each other were put. Thermal conductivity tests were performed in a guarded hot plate aparatus $\lambda$-Meter EP-500 (Germany).

## 3. TESTS RESULTS AND DISCUSSION

View of the prepared specimens for structure analysis is taken in Fig. 1. All plants are very different and individual structure. As it is known in thermophysic [23], the best heat insulating materials consist of small closed pores. In this work analysis of plants structure is performed just in such extent that macro- and micro analysis enable to evaluate structure influence on the thermal conductivity of materials.

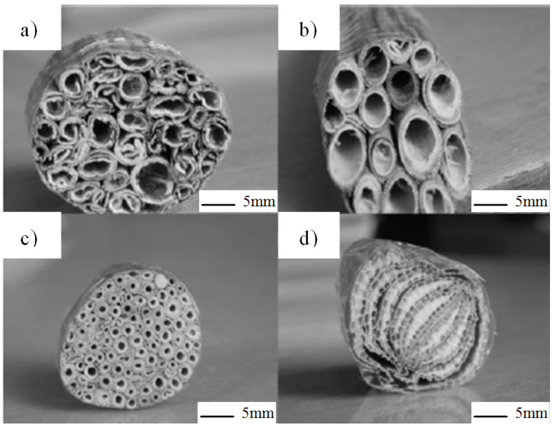
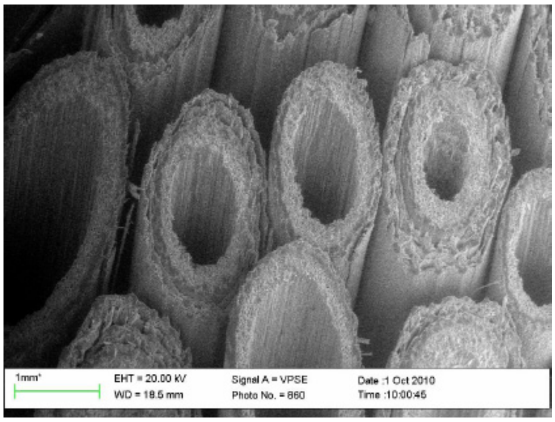



**Fig. 1.** View of prepared straw specimens for structure analysis: a – barley; b – reed; c – bent grass; c – cattail

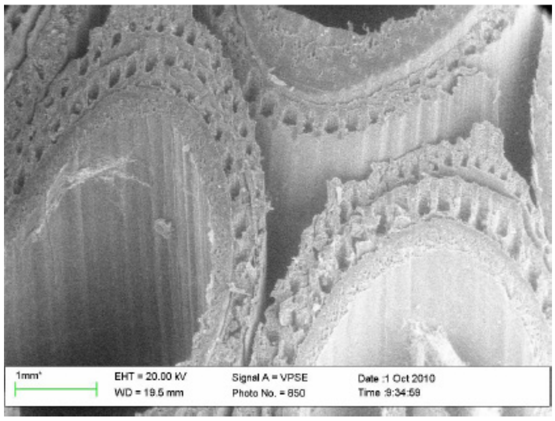
As it is seen in Fig. 1 all plants are characterized by different diameter of stalk. In forming thermal insulation material the essential task is to reduce thermal transfer by the convection. The inner diameter of barley straw and reed stalk is sufficiently larger than bent grass. Interior of cattail is fully filled with cellulose. View of macro-structure is presented in Fig. 2. The smallest diameter of stalk is of bent grass (Fig. 2, a). The diameter of bent grass changes from 2.0 mm at the bottom and to 0.5 mm – at the top of the plant. Wall thickness of bent grass is about 0.2 mm – 0.3 mm. Science the external diameter of bent grass is small, and the spacing between each of the bent grass is small too.

Reed stalks are thicker than bent grass ones (Fig. 2, b). The external diameter of reed stalk is about 4 mm – 5 mm and changes very little in all length of plant. Reed stalk consists of three layers. Two external layers are made of sufficiently large diameter (~0.3 mm) interconnected straw and inner diameter consist of about 10 times smaller inter-connected straw. All three layers are not connected with each other. Under low load these layers are easily separated. The total thickness of reed wall is 0.4 mm – 0.6 mm and thickness of individual layer is about 0.2 mm, i. e. all three layers are almost the same thickness.

Macro structure of barley straw is very mixed. Outer part of barley stalk is composed of several very thin and weak layers. Under small load outer layer is fragmented along the stalk and inner layer is deformed. Split layer fills voids between the stalks. Under larger load (formation of



a



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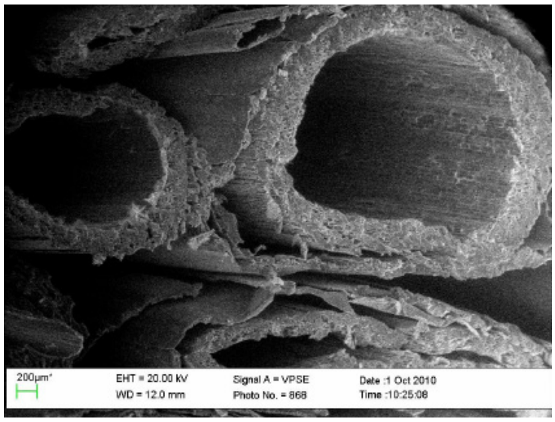

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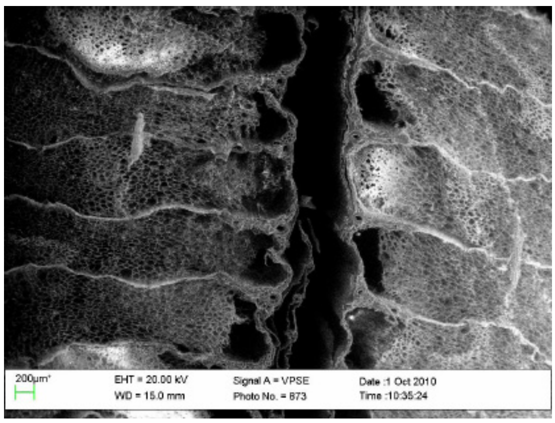

d

**Fig. 2.** View of macro structure of different plant stalks (enlargement): a – bent grass (×56); b – reed (×54); c – barley (×68); d – cattail (×62)

bales) the inner layer collapses too and stalk parts diatribute equaly in total bale volume.

From all plants structure of stalk is most distinguished by cattail. The stalk of cattail is one-piece. It consists of several reciprocally incorporated sheets. Each of these sheets is divided by thin walls into several individual areas. Every area of sheet is divided into very fine 10 µm to 50 µm open pores. Both individual cattail sheets and the stalk consist of enough strong outer walls and fully retain their processing, i. e. cutting, sorting, knotting into bales, pressing to given density. The inner layer of cattail in the individual areas is filled with very weak and brittle material.

View of plants microstructure is presented in the Fig. 3. Microstructure of plants is presented at ×250 enlargement. Bent grass, barley and reed stalks have a common feature – the outer layers are dense and low porosity and internal layers are finely porous.

Structure of bent grass and barley straw is very similar, but the outer layer of straw is very poorly and not bonded with inner layer. All layers of bent grass are bonded and looks like a one-piece layer. Bent grass inner layers consist of very small size of 0.1 µm – 1.0 µm each other interconnected straw occupying the whole length of the stalk. These straws are particularly clear on the inner surface of the stalk (Fig. 3, a). Straw stalk and the inner layer structure are very similar to the bent grass, but the inner surface of the stalk is covered by woody small-cell thick layer, not forming a porous body.

Reed wall is made up of smaller than 0.1 µm pores. Preparation of the samples showed that smaller holes are violated and just tight. This means that the smaller holes are weaker. Outer layers of the inner wall of large pores, as well as straw, covered with a thin layer of woody cells. Cattail frame forming wall is also composed of very small pores, which size is distorted preparing the sample. Cattail frame filling material consists of open small structure. Its pores vary from 10 µm to 60 µm.

Test results of thermal conductivity are presented in Fig. 4. Stalks of the plant for thermal conductivity measurement were uploaded by 2000 Pa load. In this way, the samples took the form, stability and a certain density. The maximum density of specimen is obtained by straw having a minimum diameter of the stalks – bent grass, and the smallest – having the largest diameter of stalk – cattail. Although barley straw diameter is smaller, but the density is more than 10 $kg/m^3$ lower. This resulted dense and thicker reed stalk wall.

As shown by the thermal conductivity results (Fig. 4), the highest thermal conductivity is seen of reed, while the lowest – of cattail. Comparing structure of straw bale presented in Fig. 1 and results presented in Fig. 4 the obtained thermal conductivity results are to a large extent determined by the thermal conductivity of the resulting bale structure of a void. These voids are inside the stalk, between the individual stalks and in the case of reeds inside the wall of the stalk.

This is reinforced also by the fact that significantly higher density of bent grass then reed, but thermal conductivity is enough low of bent grass.

As it is shown in [4, 24, 25], structure of the studied plant stalks is conducive to the development and

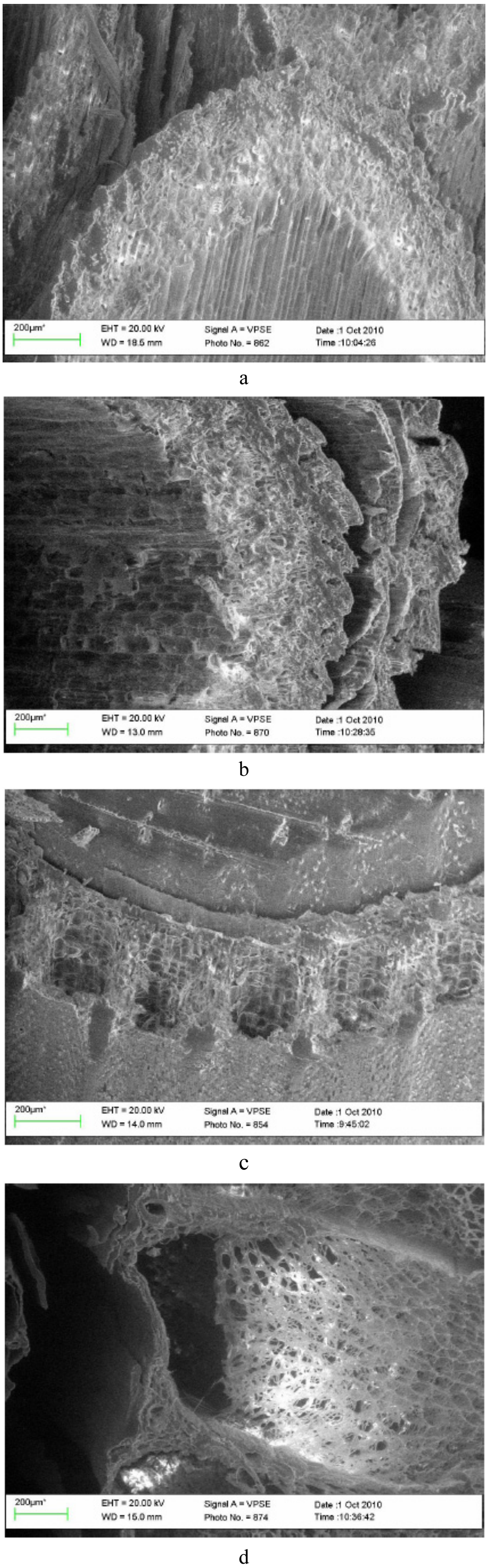


**Fig. 3.** View of micro structure of different plant stalks (enlargement ×250): a – bent grass; b – reed; c – barley; d – cattail

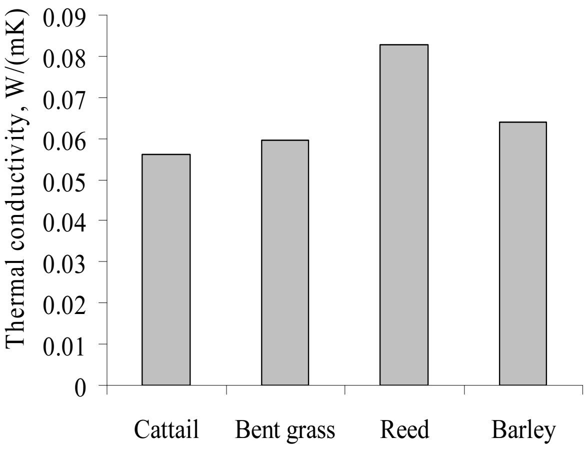


**Fig. 4.** Thermal conductivity of plant stalks. Density of specimens, kg/m$^3$: cattail – 61.5; bent grass – 110; reed – 76.5; barley – 65.2

production of thermal insulation materials while it has high porosity. However, the only comprehensive research makes it possible to identify the material that is less conductible to heat, because thermal conductivity are affected by many factors – the overall density of the product, straw orientation in the product, granulometric structure of straw, temperature-humidity regime during preparation the product, and others.

In [26, 27] it is shown that visually uniform prepared straw samples show difference between separate test results of more than three times. In our work the obtained thermal conductivity values of tested materials are close to values obtained in [28]. It should be noted that conventional thermal insulating materials – expanded polystyrene, mineral wool, polyurethane foam and others, thermal conductivity or thermal resistance of most materials are found in the thickness of the 50 mm – 100 mm. Majority of measurement equipments are customized for measurements of thermal conductivity for such material thickness. If the product is thicker, as in the case of straw bales, construction of separate elements are prepared and measurements in climatic chamber are carried out. In this case, significant differences of thermal conductivity values between the tested materials and constructions are obtained, because the connections between the individual elements during installation of construction are not taken into account or not appreciated enough and construction are heterogeneous around the area.

In the case while conventional detection devices are used, thermal conductivity measurements of straw samples at 50 mm – 100 mm thickness are not received sufficient homogeneity of the product due to the small sample thickness. In this paper thermal conductivity measurements carried out of samples up to 200 mm thickness with modern detection device are more reliable.

## 4. CONCLUSIONS

Macrostructure studies show that the biggest differences between the investigated plant stalks are void content in the prepared samples. Voids are within the same stem, forms on the formation the sample between the stalks or in the wall of the same stalk.

Microstructures analysis indicates that the barley and bent grass stalk wall is made up of small pairs of reed stem wall consisting of individual layers of large and small pairs, but latifolia stem made up of separate parts of the porous walls of finely divided into smaller areas, filled with finely porous material

For the same level of loading, thermal conductivity material has a significant impact on macrostructure - the greatest amount of cavities prepared in the sample, the heat transfer coefficient increased.

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