ENVIRONMENTAL ENGINEERING

The 8th International Conference
May 19–20, 2011, Vilnius, Lithuania
Selected papers

ISSN 2029-7106 print / ISSN 2029-7092 online
ISBN 978-9955-28-826-8 (1 Volume)
ISBN 978-9955-28-827-5 (3 Volumes)
http://enviro.vgtu.lt

DEVELOPMENT OF THERMAL INSULATION FROM LOCAL AGRICULTURAL WASTE

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Abstract. In Lithuania yearly composes large quantity of waste during processing of agricultural plants. Large quantity of these waste amounts a straw. A small part of straw is used for biofuel, the remaining part of straw is chopped and injected in the soil. Purpose of this work is to explore possibilities for production of effective insulation material from straw.

In this paper assessment of straw structure and technological factors on the thermal conductivity are presented. For the experiments straw of triticale were used. Thermal conductivity with different straw orientation and structure were measured. It was found that in the laboratory prepared samples has approximately 1.5 times lower thermal conductivity, in which majority of straw are oriented perpendicular to heat flow, than plant specimens prepared from straw bale and roll, in which majority of the straw are oriented parallel to heat flow. It was observed that increasing the density of loose straw thermal conductivity increases too, while thermal conductivity of chopped straw remains stable or declines slightly.

Keywords: waste, straw, triticale, structure, renewable sources, thermal insulation, ecological materials, energy-saving.

1. Introduction

In the crop farms of fertile soil each year composes large quantities of waste - straw (up to 6t/ha and more) that are commonly used as fertilizer. Mineralization and turn them into organic compounds in soil, when large quantities of cereals in crop structure are, is problematic (Arlauskiene *et al.* 2009, Moran *et al*. 2005).

For the straw surplus in the agricultural sector are sought opportunities to use them in other areas. One of such area is production of ecological thermal insulation materials. Thermal insulation materials from straw are ecological due two reasons: during the processing and preparation of the thermal insulation materials are not used any chemical additives, and their preparation required very small amounts of energy. For the production of all modern efficient thermal insulation materials in Lithuania illocal material are used. The easiest and cheapest way to get raw materials for the production is to use local renewable resources.

For centuries structures have been built using locally accessible materials such as straw, grass, and reed. In the African prairies, houses have been built from straw since the Paleolithic times. Many European houses built with straw or reed over two hundred years ago still stand as healthy structures today. In Germany, straw-bale construction dates back four hundred years. Roofs thatched with straw were traditional across northern Europe, Russia, and in the northern portions of eastern Asia, including Japan. The tatami floor mats of Japan are flat straw bundies with woven grass faces and cloth edges. In cold weather, the tepees of North America were insulated with loose straw between the inner linear and the outer cover. Mixtures of straw and mud comprise the second major traditional use of straw (Marks 2005).

After the invention of the mechanical hay/straw – baler in the mid of 1800 s, homesteaders in the Great Plains began turning to straw for use in construction. This was particularly evident in the north-western Nebraska during the early 1900's (Marks 2005, Gailius and Vėjelis 2010). Unlike most of Great Plains region, the thin sod that lay over the sand dunes in this area was too fragile for building sod cabins. Hay balers were first introduced in the 1850's, and by the 1890's hay presses were common. Poverty, restrictive means of transportation, and high lumber prices prevented homesteaders from building with wood. It is no surprise that between 1896 and 1945 some 70 bale buildings, including homes, farm buildings, churches, schools, offices, and grocery stores has been constructed within the region. The use of straw as a building material seemed to the easiest, cheapest, and most structurally sound option that the homesteaders had (Marks 2005).

So far, for the production of thermal insulation materials in Lithuania of small quantities are used only crop-processing residue - straw. Especially as raw material for production of such materials are not grown crops. In other foreign countries large quantities of crops are used – in Germany and Finland for thermal insulation materials are produced and used in the manufacture flax (Kymalainen and Sjoberg 2008, Samila 2009, Kymalainen *at al.* 2004), in France and the Czech Republic – cannabis (Kymalainen and Sjoberg 2008, Karus and Vogt 2004), Senegal and Estonia - reeds and cattails (Owsianowski and Nickel 2004, Maddison *at al.* 2008). In Lithuania are still the most favourable conditions for the use of straw - barley, wheat, rye and triticale. This results the initial straw processing, assembly and binding using the agricultural machinery. Meanwhile, the production of flax, hemp, reeds, cattails are needed of special agricultural technology and sophisticated manufacturing equipment.

Straw can be used in bulk, lose ground, pressed, tied up, as component in other building material or incorporated into the panels. The easiest uses of local renewable resources are a grinding material and use them as lightweight aggregate in different blocks. In the manufacture of blocks can be used virtually particles of all plant. In Lithuania for manufacture blocks are used chaff, sawdust, chopped wood, and chopped straw. In such blocks as matrix are used lime, cement, gypsum, clay and mixtures of these substances (Kazragis and Gailius 2006, Kazragis 2002).

In the manufacture of thermal insulation materials from renewable resources available thermal conductivity is approximately 0.041 W/(m·K) and even lower (Beck at al. 2004). Thermal conductivity of materials under realistic conditions may be increased. This is due to the different conditions of materials preparation in the laboratory and installation in building construction. In the laboratory usually straw are tested in bulk and their density ranges about 40 – 60 kg/m^3. Meanwhile, straw in the construction are compressed to 90 – 110 kg/m^3. Such density in the structure is required to ensure that the straw not will settle and maintain short-term and long-term loads. As have shown investigations of thermal resistance in climatic chamber (Stone 2003) the obtained results of different researchers were very different - thermal resistance of 2.5 cm layer varied from 0.176 m^2·K/W to 0.555 m^2·K/W or conversed to the thermal conductivity - from 0.041 to 0.140 W/(m·K). This difference between the results is associated with several reasons. At first, to determine thermal conductivity of thermal insulation material of large thickness is difficult due to lack of facilities or measurement accuracy, and to prepare a thin specimen from straw is very difficult and accuracy of measurement reduces too. Every time preparing straw bales changes vertical and horizontal components in straw content, their compression ratio and density. Another reason - changes moisture content in straw. On the moisture content in straw depends their thermal conductivity and the straw-making features. In the formation of too much dry straw they begin to break, and formation of too wet - straw stalks easily become clogged and increasing the overall density of the bale.

The aim of this work is to investigate thermal conductivity of thermal insulation materials from local renewable sources and the effects of straw-oriented elements on the changes of thermal conductivity.

2. Materials and test methods

For the tests triticale straw were used. Specimens from the rolls and bales were built into shields to simulation their use in building envelopes. The straws were compressed into wood shields with a constant pressure force. Surplus of straw were cut very precisely using special equipment. Straw of different orientation in the specimen, compressed or crush were used. Specimens for determination thermal conductivity were made from bales, rolls, folded and packed in bulk in pre-shredded forms. Using the bales nearly all straw are oriented parallel to the heat flow (Fig 1).

Fig 1. Specimen - 1 for thermal conductivity made from straw bale

In this way, well-equipped straw in building envelopes retain their shape even under load. In this way, well-equipped straw in building envelopes retain their shape even under load. In order to control density of straw specimen, they were placed in a wooden frame, simulating the panel structure. The second specimen was made from a roll (Fig 2).

Fig 2. Specimen – 2 for thermal conductivity made from straw roll

In such specimen large part of straw are oriented parallel to the heat flow, but some of the straw are oriented perpendicular to heat flow. In order better to clarify the effects of straw orientation in material on thermal conductivity specimens with perpendicular oriented straw to heat flow were formed (Fig 3).

Fig 3. Specimen - 3 for thermal conductivity made from perpendicularly oriented straw to the heat flow

In order to maintain the shape of specimen straw were placed between two parallel plates with bolts. By pressing the bolts was controlled density of the specimen.

The fourth specimen was prepared from chopped straw (Fig 4). The straw were cut into 2 – 4 cm in length, so that in the straw not were large air spaces.

Fig 4. Specimen - 4 for thermal conductivity made from chopped straw

For tests were used straw after processing of agricultural machinery, i.e., after grain were thrashed. Size of specimens in all cases was 500x500 mm and a thickness depended on the type of specimen preparation. Simulating panels the thickness was about 200 mm and measure oriented perpendicular to the heat flow and chopped straw - about 100 mm. Prior investigations straw were conditioned at 50 ± 5 % relative humidity and 23 ± 2 °C temperature. Using bulk and chopped straw specimens thermal conductivity was determined at different sampling densities using compressed straw panels or preload from 50 Pa to 2500 Pa.

Thermal conductivity tests were performed in guarded hot plate apparatus λ-Meter EP-500 (Germany, Fig 5.). The thermal conductivity test was determinate by according to the specifications (EN 12939:2001).

Testing thermal conductivity was carried out by guarded hot plate apparatus λ-Meter EP 500 with additional protective heating rings and cooling ring according to (ISO 8302), clause 2.1.3, Fig 5-c. Dimensions of the specimen were of (500x500) mm, the temperature difference through specimen was of 10°C. The specimens were conditioned at constant climate conditions (23±2) °C and (50±5) %.

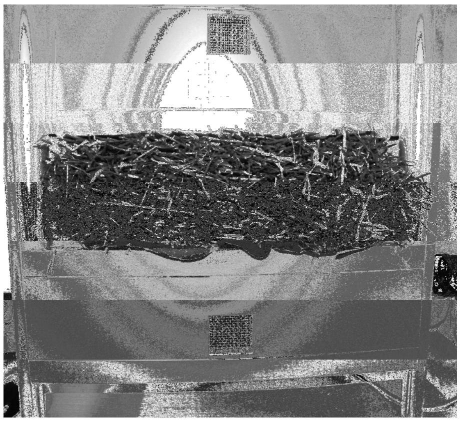

Fig 5. Thermal conductivity testing apparatus λ-Meter EP-500

3. Tests results and discussion

Thermal conductivity test results are presented in Figure 6.

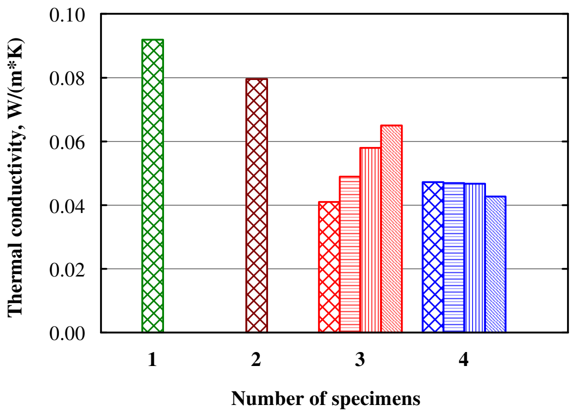

Fig 6. Measurements of thermal conductivity of straw: 1 – specimen made from straw bales; density 100 kg/m^3; 2 – specimen made from straw roll; density 90 kg/m^3; 3 – loose straw perpendicularly oriented to the heat flow; density consecutively, kg/m^3 – 50.0, 70.0, 90.0, 110; 4 – chopped straw; density consecutively, kg/m^3 – 57.0, 65.0, 76.0, 82.0

The lowest thermal conductivity has straw perpendicular oriented to the flow- (Fig 6, 3 and 4 specimens). The lowest thermal conductivity has straw perpendicular oriented to the flow- (Fig 6, 3 and 4). Thermal conductivity of specimen 3 is lowest at the lowest density – 50 kg/m^3. Increasing of density increases the thermal conductivity. When density increases 2 times the thermal conductivity increases by approximately 2.5 times. One of the reasons is increases of thermal conductivity due heat transfer through the solid shell, while still pressing the straw improves contact between the individual straws. As the stem wall of straw is porous, it may be that the densification takes place within the walls of the straw.

Meanwhile, the first specimen is formed from chopped straw, in that thermal conductivity varies very little. The lowest coefficient of thermal conductivity is achieved when the density is 82 kg/m^3. In the specimen of lower density is greater heat transfer due convection but lower heat transfer due to thermal conductivity. Such a phenomenon is observed in the measurements of thermal conductivity of modern efficient thermal insulation materials.

Thermal conductivity of specimen made from roll was 0.079 W/(m·K). High heat transfer coefficient associated with a high density of straw and straw orientation in the specimen.

In the fourth specimen, when all straw are oriented parallel to the heat flow, we can see the highest thermal conductivity - heat is intensively transfer by convection over the entire inner diameter along the straw, and over all the hard shell of straw heat is transferred by heat conduction. In this way, heat is either transfer due the most direct way and without any hindrance. Since the straw is compressed in the specimen, the heat transfer due convection is slower than in not preloaded specimen. The analysis of all four types of sampling minimum set of results is the coefficient of thermal conductivity of 0.041 W/(m·K), while the highest - 0.092 W/(m·K). In this way, the difference between the maximum and minimum thermal conductivity is 2.24 times. Other measurements of thermal conductivity of straw bales showed the difference of thermal conductivity of 3.15 times (Stone 2003). In the studies carried out with the loose straw with straw stalk oriented perpendicular to heat flow (Beck at al. 2004) thermal conductivity varied from 0.038 W/(m·K) up to 0.045 W/(m·K). This result is similar to the results obtained during current tests. Unfortunately, the description of straw orientation, density and test conditions is generally indefinable in most works. As shown in current tests (Fig 6.), the thermal conductivity is related to the straw structure, density and orientation of the straw stalk of the specimen.

4. Conclusions

1. Thermal conductivity of straw generally depends on the orientation of straw stalks in the specimen. Minimum thermal conductivity has straw stalks oriented perpendicular to heat flow, and largest - oriented parallel to the heat flow straw stalks. Compression of straw in specimen reduces heat transfer due convection very little.
2. Specific thermal conductivity is seen in chopped straw with horizontally chaotic oriented fibres. Thermal conductivity of such specimen remains almost unchanged throughout the measured range density of specimen. Increasing of density in such specimen increases heat transfer due thermal conduction, but reduces the convection heat transfer.
3. Thermal conductivity of perpendicularly oriented to the heat flow straw stalks is the lowest of the all straw specimens tested at low specimen densities. However, the density increases from 50 kg/m^3 to 100 kg/m^3, thermal conductivity increases by approximately 1.5 times. Air spaces in straw stalks by increasing density changes very little and the heat transfer due convection also changes very little, but contacts between the straw stalks are improving and heat transfer by thermal conduction increases.

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