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Manufacture parameters of thermal insulation slabs from secondary raw materials

T. Janulaitis*, L. Paulauskas**
Kaunas University of Technology, A. Mickevičiaus 37, 44244 Kaunas, Lithuania, E-mail: tadas.janulaitis@stud.ktu.lt
***Kaunas University of Technology, A. Mickevičiaus 37, 44244 Kaunas, Lithuania, E-mail: lionginas.paulauskas@ktu.lt*

1. Introduction

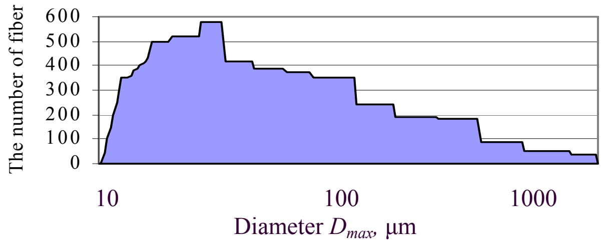
The raw materials, which have cellulose fibres such as wood refuse, refuse from wood reprocesing factories, residue from agriculture manufacture – such as cereal, flax, hemp reprocessing residue, noncultural plants such as reed, bulrush, cat's tail, domestic refuse – waste paper, cotton textile refuse can be used in manufacture of thermal insulation.

Cellulose fibres, made of waste such as used cardboard boxes, magazines, paper towels and etc. were used for manufacturing organic thermal insulation. First of all, waste was moistened and cut into small pieces using rotary mill. The obtained consistency was transported on separator transporter, while it was moving, hot air stream was blown from underneath in order to dry the cut waste. Then the cut (0.2 - 4 mm) and dried waste needs to be filamented. It is determined experimentally, that the best degree of filamenting is reached using hammer mill, which was used in preparation of thermal insulation fibres.

Thermal insulation material, used as an object of analysis, was made of powdery organic raw material mixed with synthetic polyolefin fibres, which played a the role of binding. Polyolefin fibre is a manufactured fiber in which the fiber-forming substance is any long chain synthetic polymer composed of at least 85% by weight of ethylene, propylene or other olefin units [1]. Polyolefin fibers are composed of crystalline and noncrystalline regions. Polyolefins are the products of propylene and ethylene gass polymerization. Fibrous forms of polypropylene include staple, bicomponent staple, monofilament, multifilament. Ropes and cordage, primary and secondary carpet backing, caropet face yarns, upholstery fabrics, geotextiles and etc can be made of them. The melting point of polypropylene is 160-170°C. At 130°C the fibers are soft enough to bind with organic insulation material, without harming their characteristics [2]. In such a way an organic insulation matrix is produced without using chemical substancies. The advantages of this technique include power saving and environment protection. Fiber diameter is from 10 to 35 microns [3].

2. Physical parameters determination of organic fibre

While forming thermal insulation slab comparative analysis among fibers, made of secondary assortment waste and fibres, made of waste paper, was performed. As a background of this analysis physical parameters of the fibres were taken: maximum – minimum diameters and the area of the fibre. As results of the analysis show, more homogenuous structure is observed in secondary assortment



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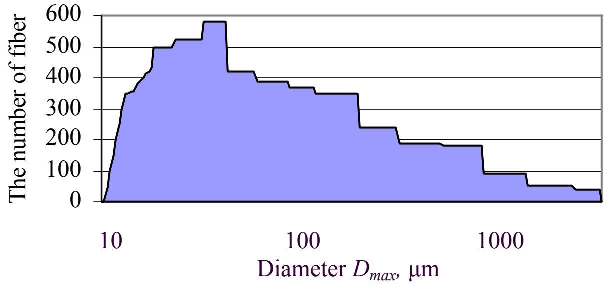
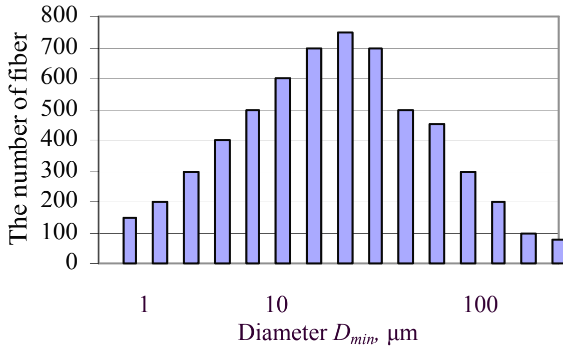


b

Fig. 1 Histogram of maximum diameter of fibres. a – waste-paper, b – second assortment waste



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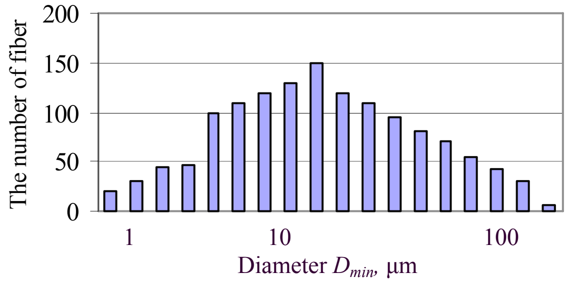

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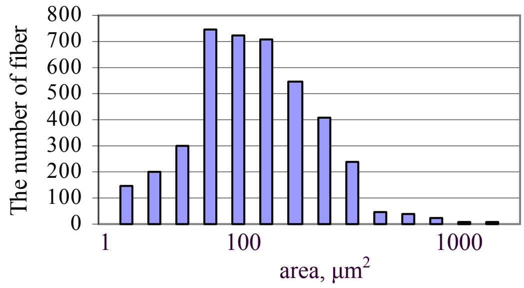
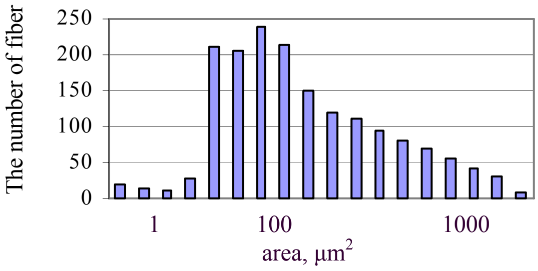
Fig. 2 Histogram of minimum diameter of fibres. a – waste-paper, b – second assortment waste



a



b

Fig. 3 Histogram of area of fibres. a – waste-paper, b – second assortment waste

fibres (Figs. 1 - 3). So this fibre was used to form organic thermal insulation slab.

3. The organic thermal insulation material, formed in laboratory conditions

The formation of the experimental new generation ecological thermal insulation slab contains following stages:

- the splint of thermal insulation material is prepared from powdery organic material (cellulose refuse, wood refuse, flax and hemp);
- the splint of thermal insulation material is mixed with a binder (in our case with the splint of polyolefin);
- with the help of hot air stream the mixture is binded and thermal insulation mat is formed [4].

To produce thermall insulation slab the specially built stand equipment was used (Fig. 4).

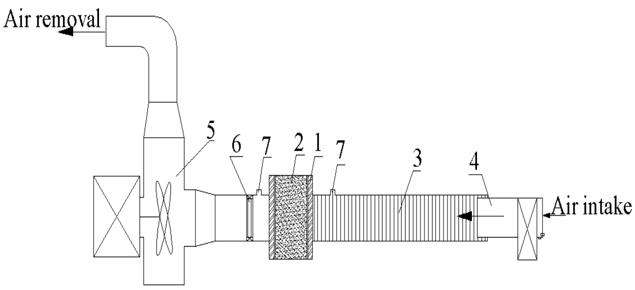


Fig. 4 The stand of formation of organic thermall insulation

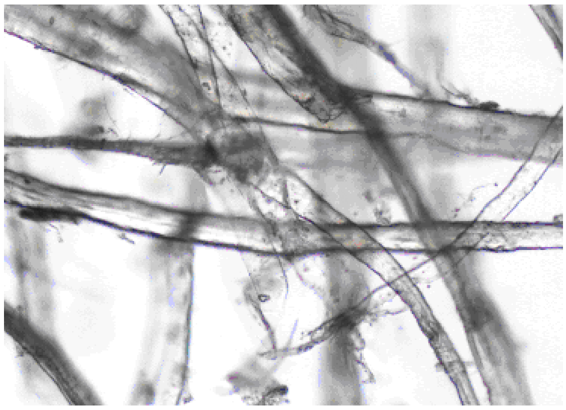
In experiment stand in box *1* powdery thermal insulation mixture *2* (organic fibres and synthetic binder) is loaded, which is binded using hot air stream (≈130°C). Air stream is generated with the help of ventilator *5*, and discharge of the stream is regulated by valve *6*. Air temperature is raised with the help of gas burner *4*. The temperature of hot air stream is equalized and stabilised in pipe *3*. The temperature is measured before the penetration through thermal insulation mixture and before the charge regulation valve, *7* – places of insertion of thermometers.

4. The macrostructure of formed organic fibre thermal insulation

By using organic fibre thermal insulation slab analysis it is determined that the structure of this material is composed of two structural levels:

- in thermal insulation material there are organic fibre derivatives, which form fibrous carcass structure;
- inter-insulation structure, made of melted fibres formed bonds of binding substance.

For the first thermal insulation macrostructure level there were determined these the most characteristical fibrous structure conformations: chaotic, the biggest part of fibres are orientated in one direction, the other part of fibres are perpendicular to the first ones; parallel, all fibres have the same orientation (Fig. 5).



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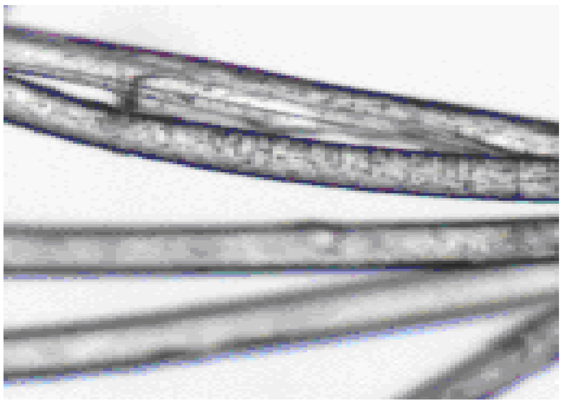

b

Fig. 5 The most characteristic fibrous structure conformations of ecological thermal insulation slab (a – chaotic structure, b – parallel structure)

It was found that such distribution of fibrous structure is determined by the degree of milling cellulose refuse wich is used to form thermal insulation slabs [5, 6].

Chaotic srtucture of thermal insulation slab (Fig. 5, a) is formed of powdery organic wool, which consists of loose fibres or of fibres that are bond to flocks only because of mechanical friction.

Parallel structural conformation (Fig. 5, b) is observed when thermal insulation slab is formed from homogeneous organic fibres.

According to allocation of binding material and formation of bonds with organic thermal insulation fibres, characteristic structural types of inter-insulation bonds could be conditionally excluded (Fig. 6).

a

b

c

Fig. 6 Possible bond structure types of fibrous thermal insulation slabs (a – too much binder and binder melting temperature was not reached; b – too little binder and binder melting temperature was exceeded; c – elastic bonds were formed)

Concerning raw material consumption and determination of thermal mode while forming a slab a and b types are not effective. In the Fig. 6, a the amount of binder was too big and the binder melting temperature was not reached. It was determined, that the most suitable melting state the binder fibres reach at 130°C. When the temperature is exceeded in the volume of general layer forming, the binder shrinks and does not connect insulation fibres, which can be seen in the type b. The most effective bonds are formed in type c, where with the help of melted binder they bind separate thermal insulation fibres into entire carcass. In inter-insulation zones this carcass forms the layer „matrix“ of fibrous thermal insulation, this „matrix“ gives mechanical strenght and rigidity to the slab. Organic fibres with not disarranged fibrous structure serves as thermal insulation material [7].

5. Interaction modeling of thermal insulation fiber and binding material

5.1. Collisional force model

When thermal insulation slab is formed using the method of hot air stream blow, interaction forces dominate among the binding material (polyolefin) and the thermal insulation fibre. The model of these forces I analyze by using algorithm of discrete element contact modelling determination technique [8]. The algorithm is developed using general ellipsoidal particles as an illustration. The operation of the model is demonstrated with a series of biaxial deformation experiments using a series of particle shapes.

The surface of the ellipsoid located at the touch point of coordinates is given by the function

$$f(x,y,z)=\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2}-1=0 \quad (1)$$

If the ellipsoid is dilated by a sphere with radius R then the dillated ellipsoid has the function:

$$f(x,y,z)=\frac{x^2}{(a+R)^2}+\frac{y^2}{(b+R)^2}+\frac{z^2}{(c+R)^2}-1=0 \quad (2)$$

Elliptical cross-sections of a pair of coplanar ellipsoids in proximity are shown in Fig. 7. Here vector $\overline{d}$ is equal to $\overline{d}=\overline{X}_2+\overline{P}_2-\overline{X}_1-\overline{P}_1$. $\overline{X}$ is the center place of the biggest part of particles.

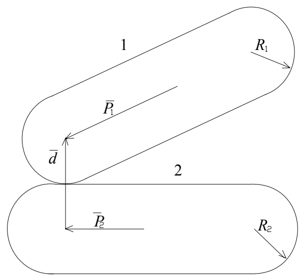

Fig. 7 The principal scheme of collisional force model. *1* and *2* respectively are the fibres of binding material and the fibres of thermal insulation fibre

The $\overline{P}$ vectors connect the particle centers to the head and tail of the $\overline{d}$ vector. The $\overline{d}$ vector is modeled as an elastic band whose ends are free to move, but are constrained to remain on the two constraint surfaces. Pulled by it‘s elasticity, the head and tail of $\overline{d}$ move iteratively to locations on the constraint surfaces that define the shortest distance between the two constraint surfaces. If the length of $\overline{d}$ is less than (R_1+R_2), then the particles are in contact. The vector $\overline{d}$, which is necessarily perpendicular to the surface of the two particles, defines the normal force to the contact surface

$$F_{no}^{i} = -\left(k_{no} A\delta_{n}^{i} + k_{no}\sqrt{A\delta_{n}^{i}}\right) \quad (3)$$

Normal strains

$$\delta_{no}^{i} = \left|\overline{d}\right| - R_1 - R_1 \quad (4)$$

The kernel of the contact detection algorithm is the set of constraints that are needed to constrain the $\overline{P}$ vectors to remain on or within the constraint surfaces.

The elastic band algorithm is implemented in the following way. The sliders that are constrained to remain on or within the constraint surfaces, whose location is specified by the $\overline{P}$ vectors, move in response to the components of the $\overline{d}$ vector that are tangential to the surfaces.

Tangential force

$$\overline{F}_{ta}^{n} = \overline{F}_{ta}^{i-1} - Ak_{ta}\Delta t\overline{W} \quad (5)$$

$$\left|\overline{F}_{ta}^{i}\right| \leq \mu F_{no}^{i} \quad (6)$$

The n denotes direction, k_{no} and k_{ta} are normal and tangential contact stiffness, i is contact viscosity, W is relative velocity of the particles at the point of contact, Δt is time step, A is matrix, μ is particle surface friction.

5.2. Frozen joint – connection force model

When the hot air stream is blown through thermal insulation mixture, the binding fibre start to melt at 130°C , in this way thermal insulation material matrix and flexible joints are formed. In order to determine nomal connection force, inter-fibre elliptical contact algorithm is applied [8].

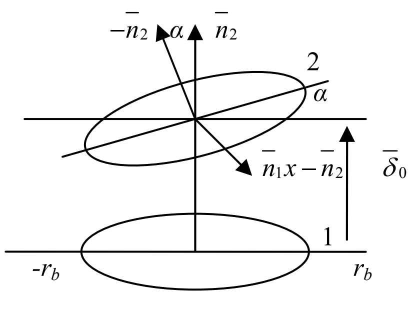

Fig. 8 Frozen joint force models

The $\overline{d}$ vectors are defined in the body frame of the particle. Initially coincident, relative motions causes the $\overline{d}$ vectors to diverge. In Fig. 8 the angle α , the deformation at the center point δ_0 , and the strain $\delta_n(x)$ at a point on the contact plane are given by

$$\alpha = \left|\overline{n}_1 x - \overline{n}_2\right| \quad (7)$$

$$\overline{\delta}_o = \overline{X}_2 + \overline{P}_2 + \overline{d} - \overline{X}_1 - \overline{P}_1 - \overline{d} \quad (8)$$

$$\delta_n(x) = \overline{\delta}_o \overline{n}_1 + \alpha x \quad (9)$$

Integrating the stress over the contact pane yields the normal force [8, 9]

$$F_{no} = k_{no} \int_{-r_b}^{+r_b} \delta_n(x)\, y(x)\, dx \quad (10)$$

here $y(x)$ – The spread of contact zone.

In Fig. 9 fiber inter-connection contact development is determined from formulae

$$r_b = \left[F_{ta}/\tau\right]^{1/2} \quad (11)$$

here τ is strains in the shear zone.

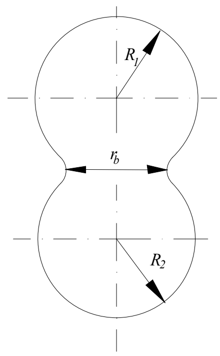

Fig. 9 Principal scheme of fibre connection

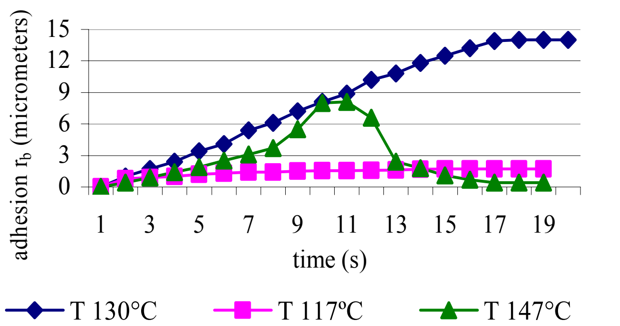

Fig. 10 Fibre adhesion dependence on temperature and time

When hot air stream is blown through thermal insulation mixture, the fibres of binding material melt and connect with thermal insulation fibres. As it could be seen from Fig. 10, the biggest radius of connection is observed, when the fibre is affected by hot air stream of 130°C temperature. This stream should be kept for 17 sec.

6. Conclusions

1. The diameter of secondary assortment waste fiber is more homogenuous than the fiber diameter of waste paper. It is advisable to form organic thermal insulation slab from secondary assortment waste.

2. While forming organic thermal insulation slab as a binding material polyolefin fibre could be used, it's melting point is at 130°C.

3. It is determined by analysis, that macrostructure of organic thermal insulation slab is composed of two structural levels: in thermal insulation material there are

organic fibre derivatives, which form fibous carcass structure; inter-insulation structure, made of melted fibres formed bonds of binding substance. Carcass structure of organic thermal insulation slab can be chaotic and parallel.

4. It is determined by analysis, that the strongest bond between the binding material and thermal insulation fibre is at 130°C temperature, which is kept for 17 seconds.

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TERMOIZOLIACINIŲ PLOKŠČIŲ IŠ ANTRINIŲ ŽALIAVŲ GAMYBOS PARAMETRAI

R e z i u m ė

Straipsnyje aprašyti Lietuvoje dar negaminamų ekologiškų organinių termoizoliacinių plokščių formavimo, pasirinkus mūsų šalyje prieinamas žaliavas, ypatumai. Ištirtas dviejų rūšių organinis plaušas: išplaušintos makulatūros ir antrinio rūšiavimo atliekų. Tyrimais nustatyta, kad reikalingo homogeniškumo struktūrą turi antrinio rūšiavimo atliekų plaušas. Išanalizuoti organinės termoizoliacijos plokštės makrostruktūriniai lygmenys, pluoštinės termoizoliacijos medžiagoje esančių organinių plaušo darinių pluoštinio karkaso struktūra ir tarpizoliacinės rišamosios medžiagos ištirpusių plaušelių jungčių struktūra. Termoizoliacinio plaušo ir rišamosios medžiagos jungčių struktūros jėgoms įvertinti pritaikytas kontaktuojančių netaisyklingų dalelių elipsoidinis algoritmas.

T. Janulaitis, L. Paulauskas

MANUFACTURE PARAMETERS OF THERMAL INSULATION SLABS FROM SECONDARY RAW MATERIALS

S u m m a r y

Formation peculiarities of ecological thermal insulation slabs, which have been not produced in Lithuania yet, are presented in this article. The chosen raw materials are available in our country. Two sorts of organic fibre, waste paper fibre and secondary assortment waste fibre, were analysed. It is determined by analysis, that the required structure of homogeneity has the fibre from secondary assortment waste. Macrostructural levels of organic thermal insulation, fibrous carcass structures of organic fibre formation located in thermal insulation material and inter-insulating binding material melted fibres bond structure were analysed. To determine forces of thermal insulation slab and binding material bond structure, the ellipsoid algorythm of contacting irregular particles was applied.

Т. Янулайтис, Л. Паулаускас

ПРОИЗВОДСТВЕННЫЕ ПАРАМЕТРЫ ТЕРМОИЗОЛЯЦИОННЫХ ПАНЕЛЕЙ ИЗГОТОВЛЯЕМЫХ ИЗ ВТОРИЧНЫХ РЕСУРСОВ

Р е з ю м е

В статье представлены особенности формирования в Литве еще неизготовляемых экологических и органических термоизоляционных панелей, используя в стране доступное сырье. Исследовано два рода органического волокна – волокно из волокнистой макулатуры и волокно из сортирования вторичных отходов. Установлено, что нужную гомогенную структуру имеет волокно отходов вторичного сортирования. Проанализированы макроструктурные ступени органической термоизоляционной панели, в волокнистом термоизоляционном материале присутствующие органические явления, структура волокнистого каркаса и межизоляционная структура связей в связующем материале растворенных волокнистых элементов. Для оценки сил структурных связей между термоизоляционным волокном и связующим материалом применен алгоритм контактируемых неправильных частиц.

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