Structural and thermal insulation products based on vegetable raw materials

O E Smirnova, A P Pichugin
Department of Construction Materials, Standardization and Certification, Novosibirsk State Architecture and Construction University, 113, Leningradskaya Street, Novosibirsk 630008, Russia

E-mail: smirnova.olj@yandex.ru

Abstract. The author of the article addresses the issues of obtaining insulation products based on flax shives. The article suggests a systematization method for the flax shives based materials, which takes into account the principle of obtaining construction materials based on flax processing waste on various types of binders. It is based on the literature data and the existing research. The possibility of using flax shives as a large structure-forming aggregate of concrete is determined along with the composition and properties of organic aggregate - flax shives. The article presents the optimal ratios selection of flax and binding bonfires in the preparation of granular materials. The characteristics of granulated aggregates on the basis of flax shives are given. The manufacture of cob granules was carried out in two technological ways: on a complex binder and on mineral binders with “dusting” with portland cement. The method involving the coating of granules with a cement shell was used to produce a granulated material with higher rates of adhesion to the hardened stone of mineral binders in the concrete composition. The technological parameters of the granulation process are determined for two technological methods.

1. Introduction
Increased requirements for thermal performance of enclosing structures, associated with energy and resource saving, lead to the need to find ways improving the thermal properties of manufactured wall materials. The effective direction of products’ quality improving from lightweight concrete is the introduction of structure-forming additives directional: pore-forming, plasticizing, air-entraining, and others [1]. However, this method leads to high material costs. The use of organic raw materials in the form of wood, reeds, flax, straw, bark, peat, etc. shive is rational.

2. Relevance
The relevance of our study is due to the fact, that thermal insulation materials, based on plant materials, are characterized by high thermal performance, the problem of recycling plant shive is solved from an environmental point of view and at the same time there is an opportunity to obtain environmentally friendly building materials.

A substantial increase in flax fiber production in Russia is planned at the state level. Thus, an increase in the acreage occupied by flax to 221,540 hectares by 2030 is planned according to the department of the agro-industrial complex report. As a rule, shives in the form of spill are practically not used purposefully and are taken to the dump where they are burned or subjected to rotting.
processes, which negatively affects the environment [2-4]. We consider the use flax shive as organic filler, which is a by-product from flax processing with sufficiently high heat insulating and shaping properties.

Analysis of literary sources showed that the production of some insulation products’ types based on flax shive has been developed. Flax shive is used mainly only as a heat-insulating material in the form of plate insulation in the civil engineering. For sure, it is advisable to consider similar types of heat-insulating materials based on vegetable raw materials for a comparative evaluation of properties. The main components of thermal insulation products based on plant shive are a binder, organic filler, and various corrective additives (antiseptics and flame retardants) are used. Various resins, polyvinyl acetate emulsion, synthetic latexes and others are used as organic binders. Liquid glass, cement, gypsum, ash and others are used as mineral binders [5-6]. A variant of materials systematization from flax shive, which is based on the principle of obtaining construction materials according to the flax processing shive on various types of binders on the basis of literature data and developed research directions, is proposed. A significant range of materials based on flax shive is divided into three groups: mineral-based materials (liquid glass, cement, active ashes, etc.), organic (urea resins, polyvinyl acetate emulsion, etc.) and complex binders [7-9].

Materials based on mineral binders, depending on a binder type, can be flax-silicate, production technology, which provides for additional mixing, by introducing a foaming agent into the binder solution and then mixing the mixture in high-speed ones. Then the mixture enters the form and, an excess of the binder solution is removed from it by evaporating, after the molded products enter the heat treatment chamber. Plastic clays are used as a binder. The water demand of the molding mixture is 28-40%, depending on the composition, if the ratio of flax to clay shive is 2:1 by weight. The average density of flax silicate products is 320–350 kg/m³, compressive strength at 10% linear deformation is 0.29–0.36 MPa, thermal conductivity is 0.052 W / mK.  

Flax magnesia materials are obtained on the basis of foamed magnesia binder and flax bonfires. The raw material mass is mixed at a low speed of a drum rotation for 10-15 minutes, after that, it is placed in special forms for 4-5 hours. Broken into pieces products are subjected to heat treatment for 5-6 hours at 110-1200°C. Products based on magnesia binder are characterized by a low density of 345-360 kg/m³, sufficient bending strength of 0.3-0.5 MPa and thermal conductivity of 0.084-0.106 W/mK [10-13].

Flax-cement materials are made according to the following technology: grinding flax shive in order to obtain an optimal fractional composition of 0.5-3 mm, its processing, component dosage, mixture preparation, laying in forms and compaction, heat treatment of molded products, aging at positive temperatures [14]. At the same time, the moisture content of aggregate should be at least 30–40%, in order to prevent moisture collection by the flax shive and dewatering the contact zone of the material structure. Water in the mixture can be introduced in three ways: in the form of mixing water, with a lock or by introducing it into the mixture in the form of a chemical solution - a "mineralizer". The average density of the samples is 430-510 kg/m³, compressive strength at 10% linear strain of 0.58-0.75 MPa, thermal conductivity 0.125-0.154 W/mK. Phenol-formaldehyde and carbamide resins, polyvinyl acetate emulsion, polymeric binders are used as binders to obtain heat-insulating materials of the second group. Porous and granular products are extruded here [15].

3. Formatting of the research problem

The flax shive has the following specific properties: low density (110 ... 120 kg/m³), low thermal conductivity (0.037 ... 0.041 W/(m ° C)), low humidity swelling not exceeding 2%, significant lignin content in organic parts up to 46%. The use of flax shive as a large structure-forming aggregate of lightweight concrete is formulated as the purpose of our work, according to the analysis of heat-insulating products obtaining based on flax shive. In order to realize the intended goal, it is necessary to solve a number of tasks: to determine the composition and properties of organic aggregate - flax shive; to select optimal ratios of flax and bonding bonfires in the preparation of granular materials; optimize the technological parameters of the granulation process [16].
4. Methods and materials

During the research work, the composition and properties of the organic aggregate were determined. Flax shive is a by-product from flax processing and one of the most common agricultural shive. Flax stems break down during fiber extraction in the process of flaking and scutching, and the falling out woody parts form shive particles [17]. The sizes of these particles vary from 1 to 10 mm in length, the thickness is in the range of 0.3 ... 1 mm. The main share of flax production and processing (about 70%) falls in the Central and West Siberian regions. Elevated concentration of lignin in the flax shive was established to 44-46%, using infrared spectroscopy, confirmed by absorption bands in the IR spectrum at 1653 cm\(^{-1}\), as well as bands in the 1540-1510 sm\(^{-1}\) area, characteristic of rings vibrations [18].

The flax shive consists of two main components - organic and inorganic like any other plant material. The organic composition of flax shive, wt.%: cellulose - 38; lignin -46; hemicellulose -10,5; fats, wax - 4,8; water soluble substances - 0.7. The study of the inorganic, ash parts of flax composition made it possible to establish the amount of ash in different parts of the same plant. It is different and depends on the degree of maturity. The content of pure ash in flax shive is 1.8%. By chemical composition, the ash part includes the following compounds: P3O4 – 5,5; K2O – 7,2; CaO - 27,2; MgO -2,3; Mn2O3 -0,4; SiO2 -13,6; SO3 -32,6; Fe3O4 + Al2O3 -10,0; Cl -0,1. Such specific properties of organic aggregates as moisture deformations, pronounced anisotropy, and elasticity are not significantly manifested in the flax shive, compared to timber.

5. The results of experimental studies

In the process of the granulate filler receiving, a fraction of flax shive no more than 2.5 mm and a bulk density of 125-130 kg/m\(^3\) was used. In order to achieve optimum values of bulk density, strength and granulometric composition of granulated materials, compositions were prepared using mineral (Portland cement, liquid glass) and organic (PVA, latex) binders. Granulation of the studied compositions was carried out on a laboratory plate granulator, with a different angle (25-45\(^\circ\)) of plate inclination and granulation time of 2-12 minutes. The original components were taken in the ratio (%, wt) of flax shive: binder 1: (1-1,15). The granules were prepared using 2 technological methods: 1 - on a complex binder, 2 - on mineral binders with “dusting” with Portland cement. The application of the method, involving the coating of granules with a cement shell is due to granulated material production with higher rates of adhesion to the hardened stone of mineral binders in concrete composition. The results of the experiment are given in 1 table.

| Table 1. Characteristics of granulated aggregates based on flax shive. |
|---------------------------------------------------------------|
| Composition | Fraction content, mm\% | \(\rho\) granulated, g/sm\(^3\) | Rssh, MPa/granule |
|---------------|------------------------|-----------------|-----------------|
|               | 15-20 mm | 10-15 mm | Less, than 10 mm |               |
| 1 way         | flax shive  + PVA    | 58,9  | 32,8  | 8,3  | 1,33 | 2,42 |
|               | flax shive  + latex   | 55,4  | 27  | 17,6 | 1,29 | 2,50 |
|               | flax shive  + liquid glass | 5,0 | 19,4 | 75,6 | 1,21 | 1,88 |
|               | flax shive  + PVA + liquid glass | 30 | 62 | 8,0 | 1,51 | 1,37 |
|               | flax shive  + latex + liquid glass | 18,3 | 46,5 | 35,2 | 1,42 | 1,46 |
| 2 way         | flax shive  + liquid glass inside the cement shell | 14 | 81 | 5,0 | 1,36 | 2,45 |
|               | flax shive  + latex + liquid glass inside the cement shell | 14 | 54,8 | 31,2 | 1,38 | 2,63 |
Crushed flax shive show a good pelletizing ability, the outcome of the 10-15 mm fraction reaches 81%, therefore this fraction is optimal and characterizes the granularity of the tested compounds. The maximum indicators of granularity are shown by flax shive, based on polyvinyl acetate emulsion and liquid glass, the outcome of fractions 10-15 mm in size is 62% and 81% for granules based on liquid glass with a cement shell [19].

The following sequence of technological operations was used in the preparation of granules on the complex binder: moistening flax shive was adding liquid glass and an aqueous polymer solution (latex or PVA) - granulation - hardening - fractionation. Granules using mineral binders were prepared according to the 2nd technological method: moistening flax shive - adding liquid glass - granulation - dusting with cement powder - hardening - fractionation. Characteristics of granular materials are given in table 2.

Table 2. Properties of granulated aggregate based on flax shive depending on the technology.

| Technological option | Fractions mm | Fraction outcome,% | Bulk density of fraction kg/m³ | Watery mass by mass for 1 hour,% | Medium strength MPa / granule |
|----------------------|--------------|-------------------|-------------------------------|---------------------------------|-------------------------------|
| 1                    | 10-15        | 62                | 335                           | 37                              | 1,37                          |
|                      | 15-20        | 30                | 287                           | -                               | 1,45                          |
| 2                    | 10-15        | 81                | 390                           | 24                              | 2,30                          |
|                      | 15-20        | 14                | 345                           | -                               | 2,52                          |

Tests of raw granules were carried out according to the guidelines for testing ashes of TPPs for agglomerite gravel production [20].

The bulk density of various fractions aggregate and compositions is 290-345 kg/m³, compressive strength is 0.5-2.6 MPa.

The effect of the mixture moisture on pelletizing was studied. For all compositions, the first signs of pelletization begin with their moisture of 22–25%. The optimum moisture content of mixtures based on flax fires is 28–33% for the 1st mode of production, and 35–40% for the second (figure 1).

Figure 1. The influence of the composition and moisture content of the mixture on its over-granulation: 1 - flax shive + latex; 2 - flax shive + liquid glass; 3 - flax shive + PVA + liquid glass; 4 - flax shive + liquid glass inside the cement shell; 5 - flax shive + PVA + liquid glass inside the cement shell. Note to Figure 1: X axis - volume fraction 10-15 mm, % Y axis - moisture content of granulated mixture, %.

In order to obtain a filler of a specific particle size distribution, the granulation process is influenced not only by material indicators (mixture composition, moisture content), but also
technological parameters, such as granulation time and tilt angle of plate granulator. The optimal time of maximum mixture pelletization according to the 1st technological method is 3-4 minutes; with the 2nd method is about 5-7 minutes. In all cases, the pelletizing time is reduced by 12-15%, using granulated mixture heated at a temperature of 500 ° C. The device of laboratory granulator allows you to change the angle of a plate aggregator inclination from 25 to 50 °.

The optimum tilt angle of the plate was determined, depending on the indicators of bulk density, raw strength and percentage outcome of 10-15 mm granules fraction [21]. The determination results of the raw granules’ bulk density, depending on the angle of a plate’s inclination, show that compounds 1-3 have the lowest bulk density, if the angle of the plate granulator inclination is 35-40 °. With a smaller and larger angle there is an increased of granulator’s small fractions outcome (less than 10 mm). Less sensitive to the process of granulation in a changing process of the plate’s angle inclination is a mixture with flax shive and liquid glass. Therefore, the angle of the plate-granulator inclination may be as low as 250 in the process of granules receiving according to the 2nd method.

The technology of preparing granular aggregates involves two main operations: granulation of the initial mixture and the implementation of the hardening process. Between these operations, the process of transportation and reloading (pouring) of molded raw granules takes place. In this regard, a mandatory criterion for the raw granules’ properties is their compressive strength. Together with an increase in the angle of the plate granulator inclination to 300, there is a short-term decrease in the compressive strength of raw granules of 10–15 mm in size, the values of strength increase if the angle of inclination increase.

A “passive” formation of granules occurs at smaller angles of the plate inclination and they do not have time to acquire a sufficiently dense and durable structure in the marked range of granulation time. With an increase in the inclination angle of more than 40 °, the fraction outcome increases to less than 10 mm. The strength of raw granules molded from various mixtures during compression varies from 0.09 to 3 MPa.

The hardening of the granules was carried out according to the regime adopted for extruded products.

6. Results
The technology to produce granulated aggregate for concrete based on flax shive was developed. 2 methods of granulating materials based on crushed flax shives were proposed, depending on the type of binder and preparation technology: single-stage and two-stage. The use of two-stage technology in the preparation of granules is due to the production of granulated material with higher rates of adhesion to hardened stone mineral binders in the composition of concrete. The mixture optimum moisture content after granulation with the maximum fraction outcome of 10-15 mm was established: for granules with a cement shell 35-40%; for granules without shell 28-33%. The technological parameters of costogranule production were determined: for mixtures on a complex binder with the inclination angle of the granulator 35-400, granulation time 3-4 min and for mixtures on mineral binders the angle of inclination was 250, granulation time was 5-7 min Concrete with an average density of 700–800 kg/m3 and compressive strength of 3.5–4.5 MPa was obtained in the process of quartz sand and large granulated aggregates using, based on flax shive as fine aggregate.

It is recommended to use granulated aggregate based on flax shive in concretes with increased noise absorbing and heat insulating ability, as a structural material for erecting internal walls and partitions, and also as a heat insulating backfill.

References
[1] Nanazashvili I Kh 1990 Building materials from wood-cement composition (Moscow: Stroiizdat) p 415
[2] Pichugin A P, Denisov A S, Khritankov V F, Ruhtsova N V 2014 Experience and possibilities of using plant materials in various objects construction Innovations and food security 3 (5) 22–28
[3] Smirnova O Ye 2017 Perspectives of Flax Processing shives in Building Materials Production 
Youth, Science, Solutions: Ideas and Prospects: a collection of scientific papers on the 
materials of the III International Young Researchers Conference 22–25 November 2016, 
Tomsk (Tomsk: Tomsk State Technical University Pub.) pp 020007

[4] Smirnova O Ye 2015 The use of waste flax processing in the construction industry Problems of reclamation of household waste, industrial and agricultural production: a collection of scientific papers on the materials 21-23 March 2015, Krasnodar (Krasnodar: Kuban State Agrarian University Pub.) pp 238–244

[5] Denisov A S, Pichugin A P, Khritankov V F, Smirnova O Ye 2019 The issue of effectiveness of plant materials use in rural construction Quality. Technology. Innovations: a collection of scientific papers on the materials of the All-Russian scientific-practical conference with international participation 19-21 February 2019, Novosibirsk (Novosibirsk: Novosibirsk State Architecture and Construction University Pub.) pp 66–71

[6] Smirnova O Ye, Ottochko S Yu 2017 Possibilities of manufacturing insulating materials based on organic waste Proceedings of NSUACE 2 (65) 120–130

[7] Smirnova O Ye 2018 Physical-mechanical and operational properties of extruded heat-insulating products based on flax shives Physical and chemical processes in building materials science: a collection of the International Scientific-Technical Conference 18-20 February 2017, Novosibirsk (Novosibirsk: Novosibirsk State Agrarian University Pub.) pp 204–208

[8] Smirnova O Ye 2018 Influence of flax shives on the properties of pressed material Resource-efficient and energy-efficient technologies in the construction complex of the region: a collection of scientific papers on the materials of the VI International Scientific and Practical Conference 16-18 April 2018, Saratov (Saratov: Saratov State Technical University Pub.) pp 152–157

[9] Smirnova O Ye 2006 Building insulation materials based on waste of flax processing Proceedings of NSUACE 1 (22) 142–148

[10] Smirnova O Ye 2007 The use of waste flax processing for the production of insulation products Izv. Universities Building 3 42–46

[11] Bazhenov Yu M 2003 Concrete technology (Moscow: ABC) p 500

[12] Krutov P I, Sklizkov N I 1978 Building materials from local raw materials in rural construction (Moscow: Stroiizdat) p 284

[13] Solomatov V I 1980 Elements of the general theory of co-positioning materials Izv. Universities Construction and architecture 8 61–70

[14] Khozin V G, Shekurov V N, Petrov A N 1997 Complex use of plant materials in the building materials production Construction Materials 2 12–14

[15] Kolesnikov V S 1975 Research of heat-insulating building materials on the basis of plant wastes of Kazakhstan agricultural production and industry composition (Moscow: Stroiizdat) p 25

[16] Guidelines for testing ash TPP for the production of aglo porite gravel (Moscow: VNIIstrom) p 17

[17] Klassen P V, Grishaev I G 1982 Basics of granulation technique (Moscow: Chemistry) p 272

[18] Itskovich S M, Chumakov L D, Bazhenov Yu M 1991 Technology of concrete aggregates (Moscow: High Schoo) p 272

[19] Gorlova Yu P 1987 Artificial porous aggregates and lightweight concretes composition (Moscow: Stroiizdat) p 304

[20] Zavadsky V F 1995 Non-autoclaved lignogazobeton Izv. Universities Building 2 65–67

[21] Gorlov Yu P Technology of thermal insulation and acoustic materials and products (Moscow: Higher school) p 384