

**RIGA TECHNICAL UNIVERSITY**

**Olita MEDNE**

**RESEARCH ON EXPANDED POLYSTYRENE  
PRODUCT MANUFACTURING PROCESS**

**Summary of Doctoral Thesis**

**Riga 2011**

**RIGA TECHNICAL UNIVERSITY**  
Faculty of Materials Science and Applied Chemistry  
Institute of General Chemical Engineering

**Olita MEDNE**  
PhD Student of the Doctoral Study Programme „Chemical  
Engineering”

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Scientific Supervisor:  
Docent, Dr.sc. ing. I. DREIJERS

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**DOCTORAL THESIS  
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IN THE FIELD OF CHEMICAL ENGINEERING  
IN THE SUB-FIELD OF GENERAL CHEMICAL ENGINEERING**

Doctoral Thesis for obtaining a doctor's degree in engineering sciences will be publicly defended on December of 27<sup>th</sup>, 2011 at Riga Technical University Faculty of Materials Sciences and Applied Chemistry, 14/24 Āzenes Street, room 272.

OFFICIAL OPPONENTS

Profesor, Dr.sc.ing. Jurijs Ozoliņš  
Riga Technical University

Dr.habil.chem. Fricis Avotiņš  
Riga Technical University

Dr.chem. Viesturs Zeltiņš  
Latvian State Institute of Wood Chemistry

CONFIRMATION

I confirm that I have elaborated Doctoral Thesis which I submitted for consideration at the Riga Technical University for acquisition of a Doctoral degree in engineering sciences. The present Doctoral Thesis is not submitted in other scientific institutions for acquisition of a scientific degree.

Olita Medne .....

Date: .....

The Doctoral Thesis is written in Latvian, it contains introduction, literature review, experimental part, results and analysis, conclusions and the list of used references. The Doctoral Thesis contains 127 pages, 99 pictures, 15 tables and the list of 86 references.

## GENERAL DESCRIPTION OF THE WORK

**Topicality of the research.** The expanded polystyrene products have been widely used as insulation materials already for decades. [1]. Its manufacturing amount in one of the companies in Latvia reaches 100 000 m<sup>3</sup>/ year.

The manufacturing of the expanded polystyrene products is a multi-step process that depends on extremely high (> 40) mutually correlated number of parameters.

The structure of granule expanded polystyrene (EPS) products in large-size blocks is not homogeneous regarding to density, fusion level, porosity, mechanical tensions, strength and other factors. Homogeneity is very dependent on manufacturing technologies and raw material properties. As the result of heterogeneity cracks, inner tensions (that cause curving of the cut slabs) and non-compliance with norms of thermal or mechanical properties can be caused. Only products that comply with the norms get in the market. Recycling of low quality products causes loss of raw materials for the manufacturer, as well as gives unnecessary consumption of energy resources and increases emissions. Purposefully studying the manufacturing process of granule expanded polystyrene products it is possible to decrease waste and to prevent consumption of uselessly consumed resources.

The analysis of literature data leads to the conclusion that the manufacturing process of granule expanded polystyrene products from large-size blocks practically has not been studied. No correlations have been found for the changes of the EPS product properties in the large-size block depending on the applied technological parameters in industrial conditions. The experiments on small size models reviewed in the literature cannot be transferred and applied to the real manufacturing processes.

### **Aim of the Thesis**

The **aim of this Thesis** is to study and define the regularities influencing the division of the EPS product properties in the large-size granule expanded polystyrene block volume depending on technological parameters. Basing on the research to optimise the manufacturing technology for granule expanded polystyrene large-size blocks in industrial scale manufacturing equipment, thus improving the quality of the products.

The research was carried out in cooperation with the company SIA „Tenapors”.

### **The following objectives have been set for the achievement of the aim:**

- on the basis of literature data analysis to evaluate the influence of manufacturing parameters on the properties and structure of the products;
- to analyse the technological process in the industry (in the company SIA “Tenapors”);
- to analyse the influence of the raw material granulometry on properties and structure of industrially manufactured products;
- to evaluate and identify the main technological parameters that cause the inner tensions and property heterogeneity in large-size block volume;

- to analyse the division of mechanical parameters of the industrially manufactured EPS products over large-size block volume at different manufacturing regimes;
- to recommend modes and methods for improvement of the finished product quality.

**Scientific significance and novelty of the Thesis:**

- for the first time based on systematic research on industrial scale manufacturing process the heterogeneity of mechanical properties of the expanded polystyrene products over the large-size block volume was studied according to the manufacturing parameters and used raw materials;
- the distribution of steam flow and its influence on polymer granule layer in the EPS block volume was analysed;
- the influence of steam flow on closed porous polymer granule expansion and fusion depending on the steam feeding intensity was analysed;
- correlations between density, compressive strength and tensile strength and the EPS block quality were determined.

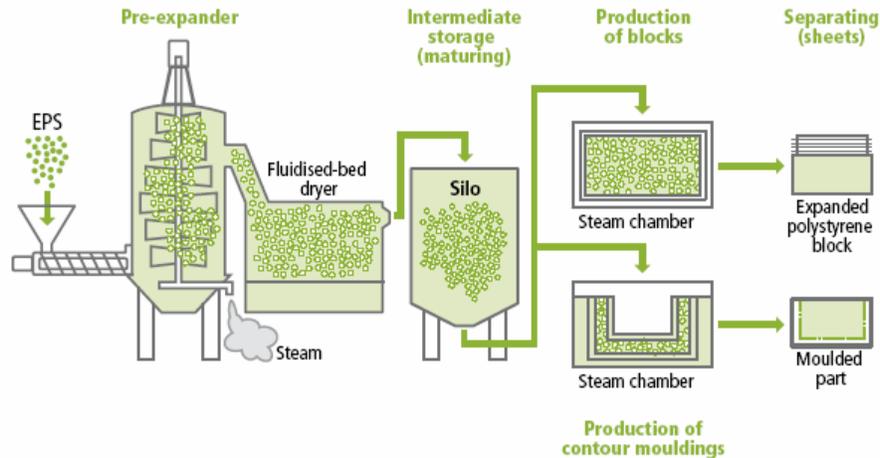
**Practical significance of the Thesis:**

- the influence of moulding process parameters on the expanded polystyrene product properties and property dispersion in large-size blocks has been defined;
- the set of manufacturing technological parameters for obtaining more homogeneous expanded polystyrene products and improvement of quality has been developed;
- specific recommendations for the improvement of quality for expanded polystyrene products have been developed (for decrease of mechanical property heterogeneity by 15%);
- the obtained data has been practically used for improvement of product manufacturing technology in the company SIA “Tenapors”.

## LITERATURE REVIEW

In the literature review the publicly available information was evaluated for the period from year 1981 to 2010. The analysis has been made on materials of scientific literature and technological information on the manufacturing process of the expanded polystyrene products that includes: pre-expansion of raw material, stabilisation of the pre-expanded material, EPS block moulding, stabilisation of the finished blocks and cutting in slabs (Pic.1).

Description of the expanded polystyrene product contexture and structure has been given. The influence of process parameters on product properties was analysed.



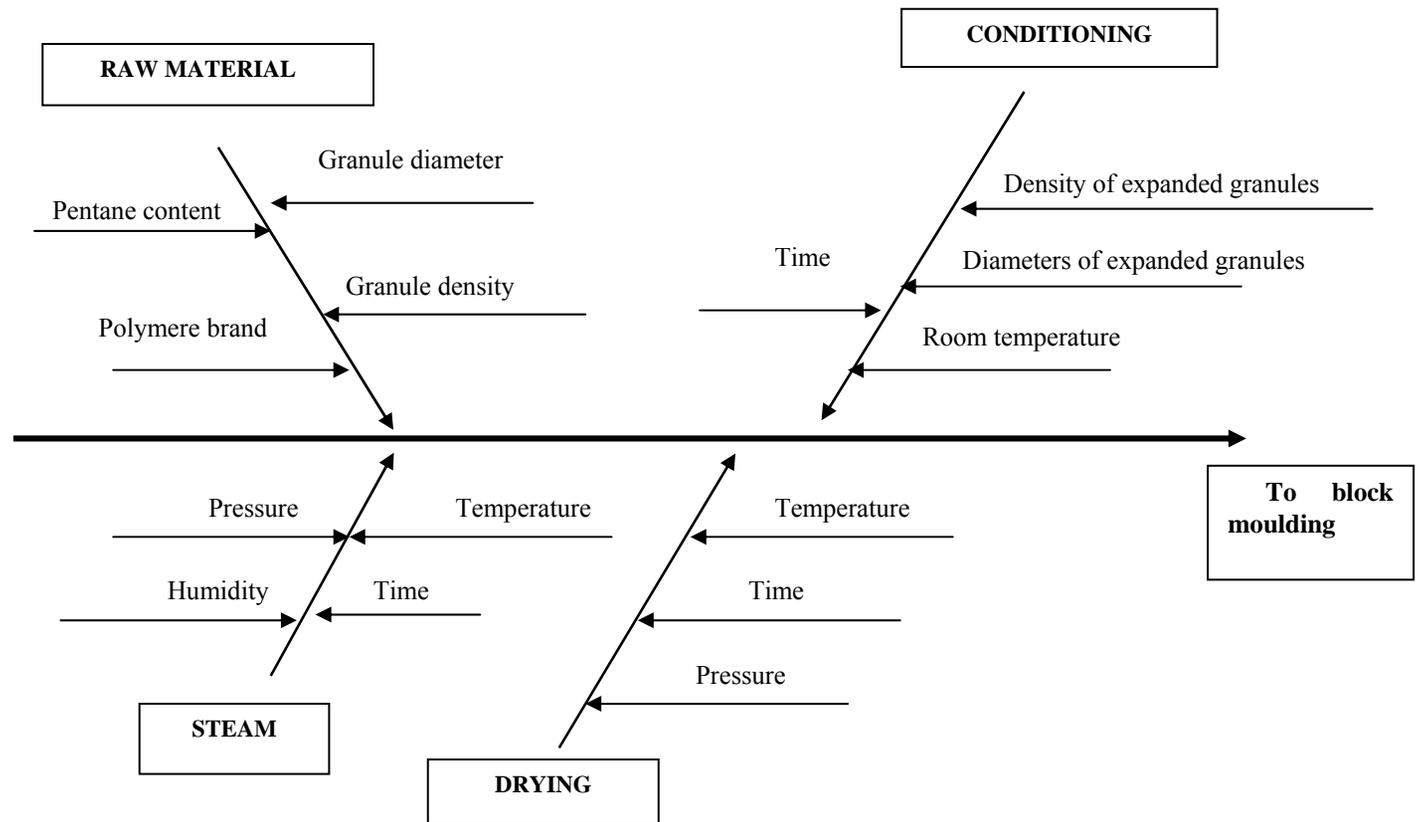
Pic. 1. The manufacturing technological process of the expanded polystyrene products [2]

From the literature review and analysis of the manufacturing process in the company SIA “Tenapors” where the experiments were carried out, it was stated that the manufacturing process of the EPS products from large-size blocks is a complicated multi-stage process. It depends on a very large number of mutually correlated parameters. It is practically not possible to make the optimisation of the process by varying all parameters. Thus a quality cause-effect analysis of large-size block manufacturing process and its products was carried out in order to identify the most important parameters and their mutual correlations.

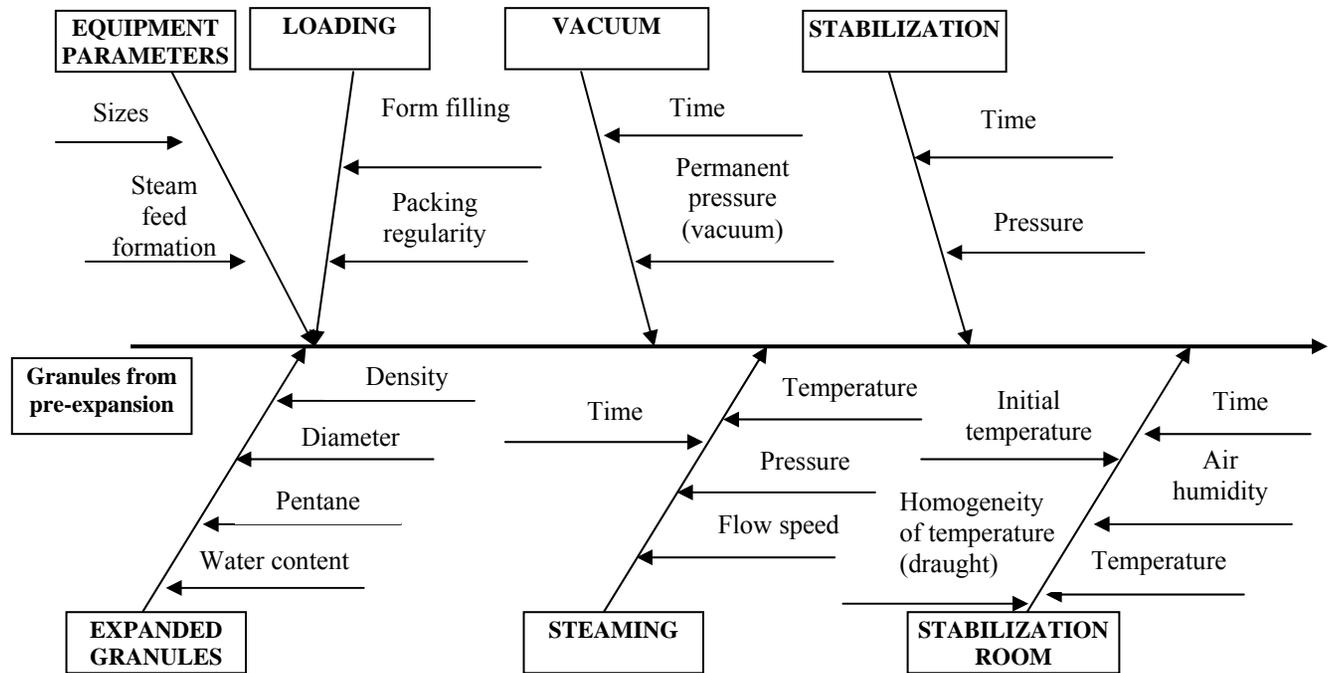
The main guidelines of the literature review for the pre-expansion and moulding process are reflected in Pictures 2 and 3.

From the pre-expansion cause-effect diagram it can be concluded that one of the defining factors for the end product quality is the raw material properties, but for the moulding process the following were chosen as the most significant for the research:

- the characteristics of the expanded granules – size, density, structure and conditioning time of the granules;
- the change of block mould steam parameters – speed, direction, pressure and processing time of the flow.



Pic. 2. Parameters influencing pre-expansion process



Pic. 3. Parameters influencing moulding process

## SAMPLE PREPARATION AND RESEARCH METHODS

### 1. The used raw material and sample preparation

For the manufacturing of expanded polystyrene products the raw materials with differing granule diameter, granulometry and pentane content were used. Description of the raw material has been given in Table 1, where granules with bigger diameters are D and E, but with smaller diameters – B, C, G.

Table 1

Description of the used raw material

| Raw material brand/<br>manufacturer | Pentane<br>content,% | Granule<br>sizes, mm | Description |
|-------------------------------------|----------------------|----------------------|-------------|
| Styopor F395 / BASF                 | 4,1 – 4,6            | 0,7 – 1,1            | B           |
| Styopor F295 /BASF                  | 4,1 – 4,6            | 1 – 2,3              | D           |
| NF-714/StyroChem                    | 6 – 7                | 0,7 – 1,1            | C           |
| RF23M/ IneosNOVA                    | 5                    | 0,9 – 1,5            | E           |
| RF33M/ IneosNOVA                    | 5                    | 0,6 – 1,1            | G           |

\*- For block marking the marks are used – a letter with attached number, for example, for the raw material F295, D1 or D2, that indicate that the manufacturer's batch, granulometry differ for these raw materials.

The samples were prepared according to the technological process given in Picture 1, using real manufacturing equipment:

- for granule pre-expansion – continuous expander (Hirsch Preex 1200);
- for block moulding – blockform with sizes 4m x 1m x 1,2 m (Kurtz VSD 4600).

#### Pre-expansion

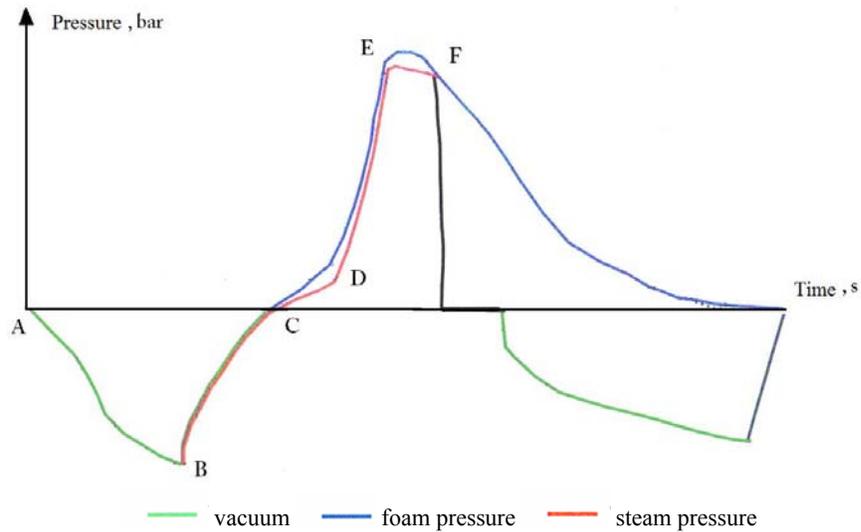
For each raw material slightly differing pre-expansion conditions (according to material parameters) and successive granule conditioning were used.

#### Block moulding

In Picture 4 a cycle curve of a typical expanded polystyrene block moulding has been showed, that reflects the change of vacuum, steam pressure and foam pressure values in time.

In the experiments different technological parameters of expanded polystyrene block moulding were used, varying pressure and time:

- in the vacuum stage;
- in the atmosphere pressure reaching and primary steaming stages;
- in the steam shock stage.



Pic. 4. Curve of block moulding parameters [3]

AB – vacuum stage; BC - atmosphere pressure reaching stage;  
 CD – primary steaming; DE – steam shock; EF – dwell steaming

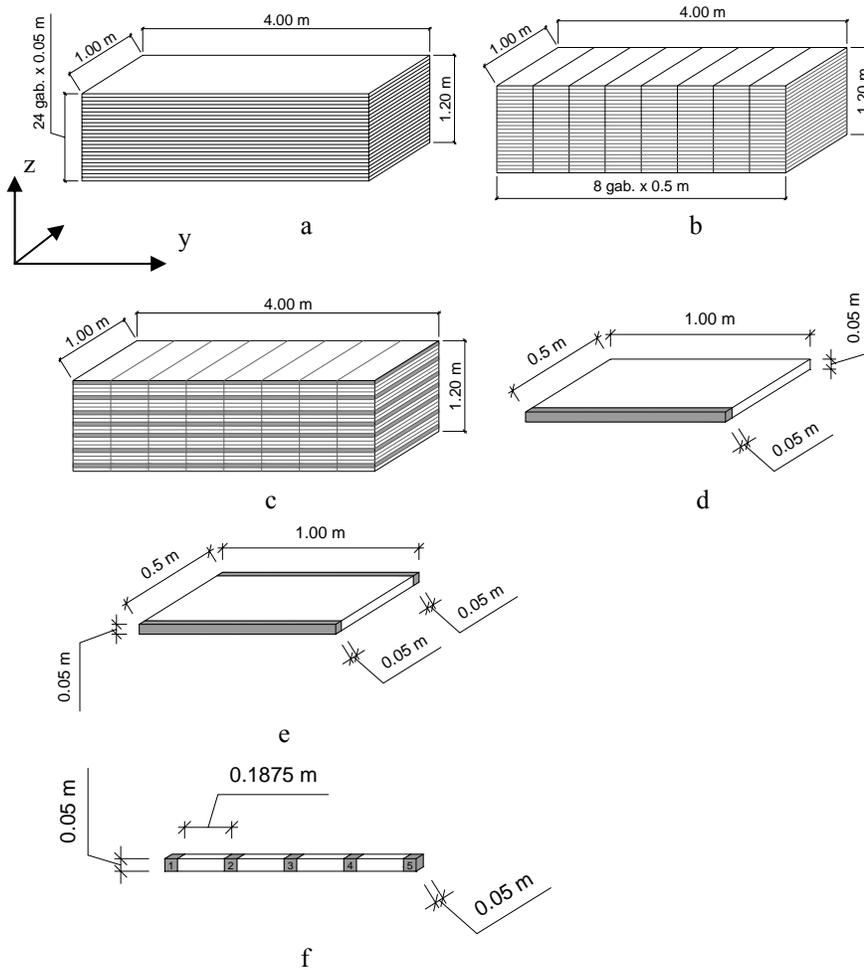
## 2. Sample preparation from expanded polystyrene blocks

The sample size, location and direction how they are taken out of the block have significant influence on the analysis of block properties, especially on homogeneity [4].

From the manufactured EPS block (with dimensions 4m x 1m x 1,2m) that has been conditioned in room conditions ( $20 \pm 3$  °C) samples of (50 x 50 x 50) mm were cut out.

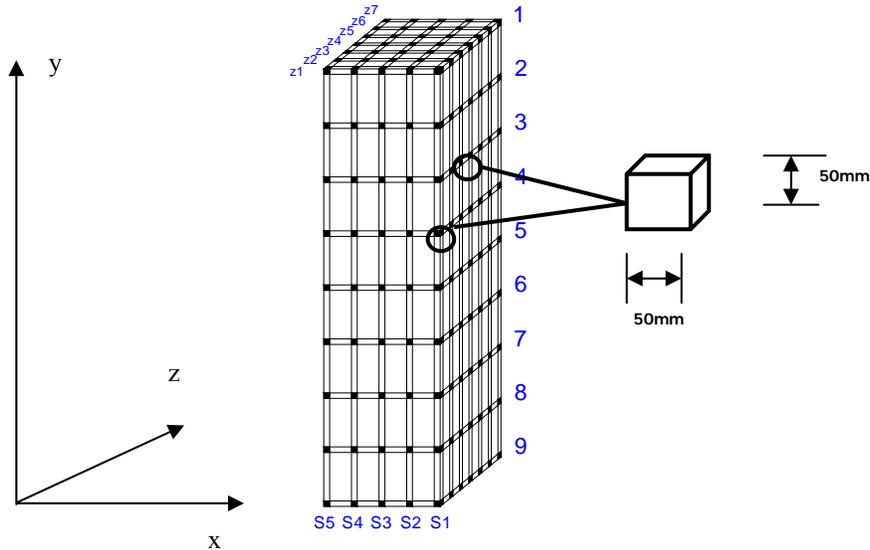
First the block is placed on one side on the cutting line with known blockform door direction. Hot longitudinal wires cut the block in twenty four slabs with dimensions 4m x 1m x 0,05 m (Pic. 5.a). Each of these slabs that are placed onto one another are cut in 8 strips with vertical wires in such a way that the size of each strip is 0,5 m x 1m x 0,05m (Pic. 5.b). Out of all strips 56 pieces are chosen, marked in grey in picture (Pic. 5.c). From 49 strips slips are cut off from the right side with dimensions 0,05 m x 0,05 m x 1 m (Pic. 5.d), but from the remaining 7 strips that are placed on the left side of the horizontally laid block slips of the same size (Pic. 5.e) are cut off from both longer sides of the strip. From the cut slips 5 samples of dimensions 0,05 m x 0,05 m x 0,05 m are cut out from exactly marked places (Pic. 5.f) and the sample number is fixed that gives opportunity to compare the obtained data of one block to the data samples of another block that are located in the same block places.

Thus 315 samples are cut out of each block for further definition of mechanical and other properties.



Pic. 5. Sample preparation from the EPS block

In the further text the samples are identified with unique denomination of the tested block and sample location in the block. Thus,  $z_1, z_2 \dots - z_7$  denominates the slab number from the block front side; 1, 2 ... to 9 (y axis) – number of the vertical strip in the given slab  $z_i$ , but S1, S2 ... to S5 – sample number in the strip (see Pic. 6). The location of 315 samples in the block is showed in Picture 6.



Pic. 6. Sample location in the EPS block

### 3. Research methods

For the research of the raw material the defining of granulometry is used.

For the research of pre-expanded polystyrene the following methods were used:

- study of pre-expanded granule structure;
- defining of granulometry.

For the characterising of the obtained expanded polystyrene product properties the following were defined:

- compressive strength at 10% deformation;
- density;
- tensile strength;
- long-term water absorptions, completely immersing in water;
- thermal conductivity coefficient.

The properties of the samples are tested according to EN 13163 and to its binding norms - compressive strength at 10% deformation (EN 826), tensile strength (EN 1607), density (EN 1602) and longterm water absorptions, completely immersing in water (EN 12087).

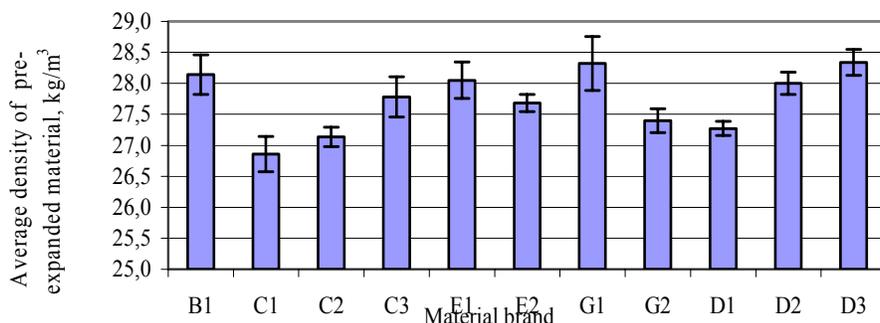
Intermediate products and the obtained products have been studied using range of up-to-date research equipment:

- the scales Kern 440 were used for defining of weight of the samples;
- for the defining of granulometry the equipment AS200 with mechanical screening was used;
- for the study of granule microstructure the scanning electronic microscope (SEM) Mira\ LMU (Tescan) was used;
- for the sample macroscopic studies the stereomicroscope Leiz MZ 16 A, DFC490 was used;
- for the defining of tensile strength of the samples the equipment Tinius Olsen H25T was used;
- for the defining of thermal conductivity coefficient of the samples the equipment of series LaserComp FOX600 was used;
- the material test in compression was made using the equipment Instron 1011, 4301.

## RESULTS AND DISCUSSION

### 1. Pre-expansion

The pre-expansion of expanded polystyrene raw material is a very significant process. The density of the obtained product depends on this stage. Using raw materials of different granulometry, granule size and pentane content their pre-expansion conditions have to be chosen different. In order to ensure the necessary density of the finished product  $30 \text{ kg/m}^3$ , the density of the pre-expanded granules has to be within limits of  $26,5$  to  $28 \text{ kg/m}^3$ . In the experiments different raw materials were used (raw material description is showed in Table 1) with varied average density of the pre-expanded granules (Pic. 7).



Pic. 7. Average density of the pre-expanded polystyrene granules

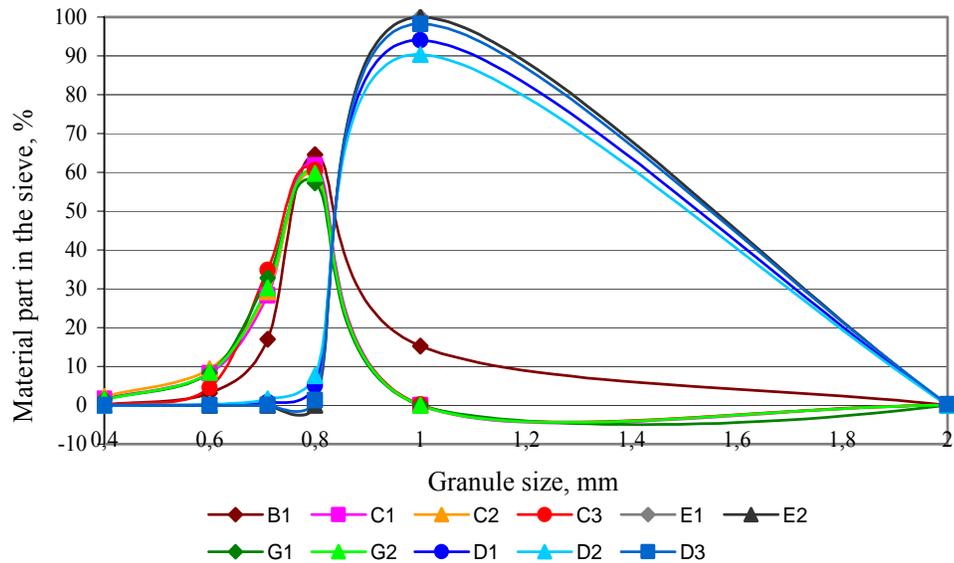
## 2. Changes of granulometry

In order to define the changes of granulometry during the pre-expansion, the granulometry for non-expanded polystyrene granules and pre-expanded polystyrene is stated.

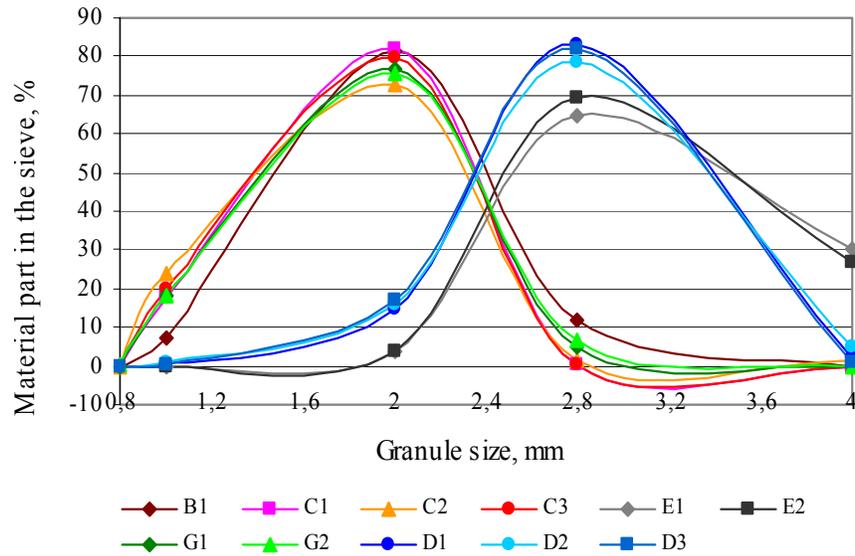
The obtained data on division of granulometry for non-expanded polystyrene granules are reflected in Pic. 8.

As can be seen the used materials according to granule size division can be grouped in two pronounced groups; one with maximum 0,8 mm and other with maximum 1 mm. Both divisions are with marked asymmetry (B1, C1, C2, C3, G1, G2 in negative direction, E1, E2, D1, D2, D3 – in positive direction). It can be noted that also different batches of one and the same material can differ according to their granulometry, as it is observed comparing samples D1 and D2 to D3.

Granulometry for expanded polystyrene granules are reflected in Picture 9. It can be concluded that expanded polystyrene granules in general expand proportionally to the maximum size of non-expanded raw material granules and the character of division (asymmetry) does not change.

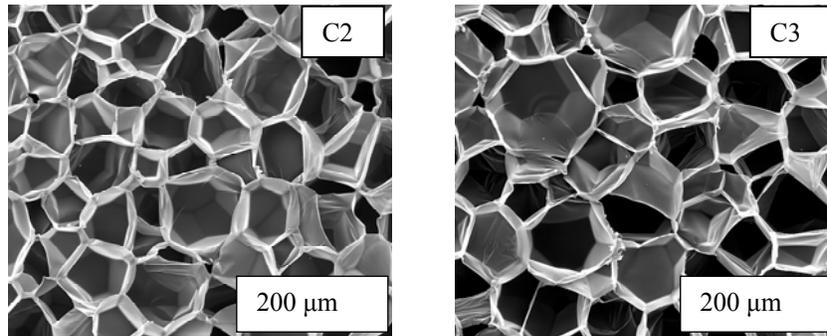


Pic. 8. Granulometry of non-expanded polystyrene granules

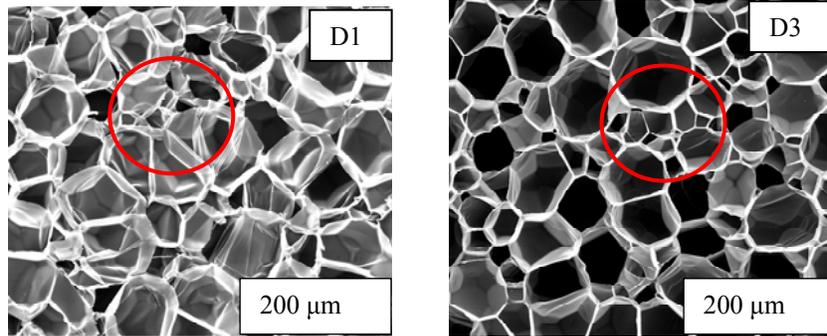


Pic. 9. Granulometry of pre-expanded polystyrene granules

**3. Influence of pre-expansion process parameters on the EPS granule structure**  
 Based on the cross-section of separate pre-expanded polystyrene granules in SEM microphotographs it was stated that differences in granule cell sizes and division for the granule structure are observed (Pic. 10).



Pic. 10. SEM microphotographs for granules of different raw materials



Pic. 10. (cont.) SEM microphotographs for granules of different raw materials

In the structure of the pre-expanded polystyrene granules from the raw materials - D1, D3, E1 and E2 – small cells were also found that could be characteristic to expanded polystyrene granules with size within limits 0,8 – 2 mm, when their cell growing processed with steam do not happen as steady as in granules with smaller granule diameter 0,6 – 1 mm.

The size of pre-expanded polystyrene granule cells depends on expansion parameters. It can be concluded that the selected pre-expansion parameters ensure the expansion of different raw materials to the necessary density (26,5 – 28 kg/m<sup>3</sup>).

#### 4. Conditioning of the pre-expanded polystyrene

Analysing the dependence of the stabilisation time of different applied raw material moulding process on the conditioning time of the pre-expanded granules, in experimental way the optimal stabilisation times were determined that ensure block quality and non-cracking. The conditioning times of the used raw materials are shown in Table 2.

The conditioning time has direct influence on block moulding parameters. Although pre-expanded granules with density 27 – 28 kg/m<sup>3</sup> can be moulded already after 24 h conditioning, the granule sizes and pentane amount should be taken into account as they influence the stabilisation time in further block moulding, thus the pre-expanded polystyrene granules with sizes within limits of 0,8 – 2 mm have to be conditioned slightly longer. The bigger the size of granules, the slower the process of gas exchange [5].

Table 2

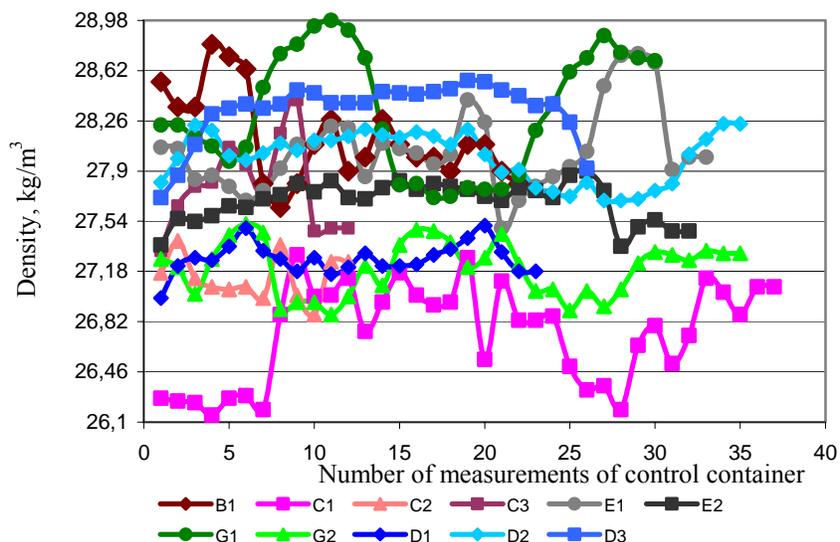
Conditioning times of pre-expanded granules  
and stabilisation times of moulding process

|              |           | Conditioning time of pre-expanded polystyrene, h | Stabilisation time in moulding process, s |
|--------------|-----------|--|---|
| Raw material | <b>B1</b> | 40   | 110-120                                   |
|              | <b>C1</b> | 21   | 200-220                                   |
|              | <b>C2</b> | 24   | 200-210                                   |
|              | <b>C3</b> | 24   | 200-210                                   |
|              | <b>E1</b> | 69   | 200-210                                   |
|              | <b>E2</b> | 65   | 200-240                                   |
|              | <b>G1</b> | 42   | 100-110                                   |
|              | <b>G2</b> | 64   | 100-110                                   |
|              | <b>D1</b> | 43   | 200-250                                   |
|              | <b>D2</b> | 46   | 200-250                                   |
|              | <b>D3</b> | 72   | 120-130                                   |

Granules with sizes 0,6 – 1 mm compared to more rough granules (0,8 – 2 mm) have shorter moulding stabilisation times, it is seen, for example, comparing raw materials B1 and D1. However, in case of raw material G the optimal granule conditioning time has been found. Despite the differing conditioning time of raw material batch pre-expanded granules, the stabilization times of G1 and G2 in block moulding are equal.

#### **5. Sensitivity of expanded polystyrene raw material in pre-expansion process**

The pre-expansion process is the main factor determining the EPS product density. For getting the necessary density we use a single pre-expansion. During the expansion process, the equipment ensures the set material density by controlling it with standard volume container. The fluctuations of density values of this container for each raw material batch in continuous pre-expansion process are shown in Picture 11.



Pic. 11. Sensitivity of expanded polystyrene raw material in pre-expansion process

Despite the fact that the process is stationary and uninterrupted significant fluctuations of density values of separate control containers have been observed.

Higher fluctuations of density of pre-expanded polystyrene portions are shown by raw materials with smaller granule diameter – B, C and G. It could be explained by the fact that smaller diameter granules react faster on the steam flow. The steadiest fluctuations of portion density in the pre-expansion is shown by the raw material D.

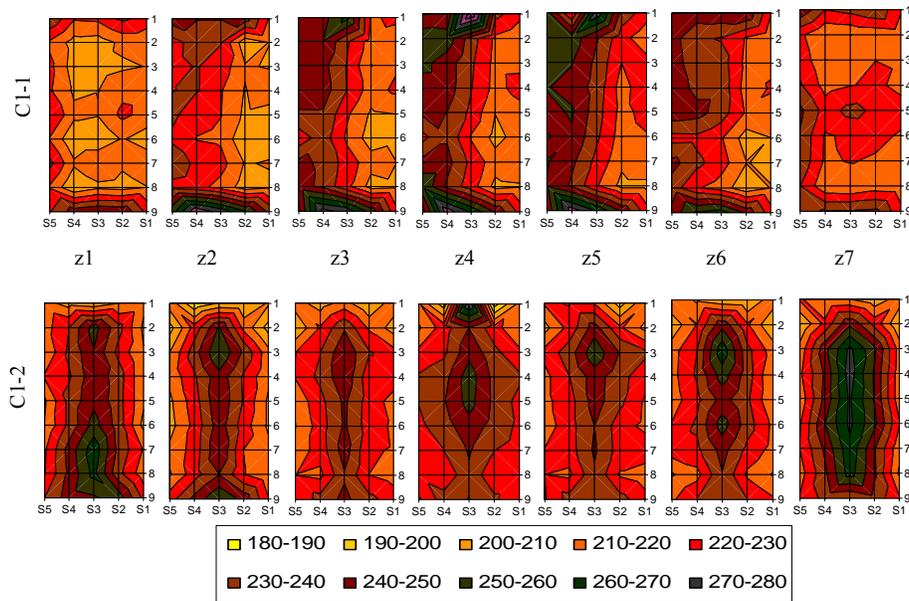
#### 6. Research on block moulding process

In the Thesis the experimentally obtained results for the expanded polystyrene products were evaluated depending on block moulding technological parameters for different raw materials (see Table 1). The division of property irregularity of expanded polystyrene product samples cut out of large-size blocks has been analysed using compressive strength, tensile strength, density, macrostructure.

It has been experimentally ascertained that the expanded polystyrene product samples cut out of large-size blocks that have been prepared ensuring constant set parameters within limits of one batch show similar properties. Thus for further comparison and characterisation of product properties two or three blocks have been used. By analysing 47 blocks interconnections of technological parameters and mechanical properties have been found.

### Influence of steam flow directions on product homogeneity in the block

Two different types of steam flow direction realisation was studied, in order to define their influence on expanded polystyrene product properties in the blocks: programme P1 – with steam feeding flow from the blockform in one direction and programme P2 – with steam feeding flow in two opposite directions. C1-1 block was prepared using P1, the block C1-2 by using P2.

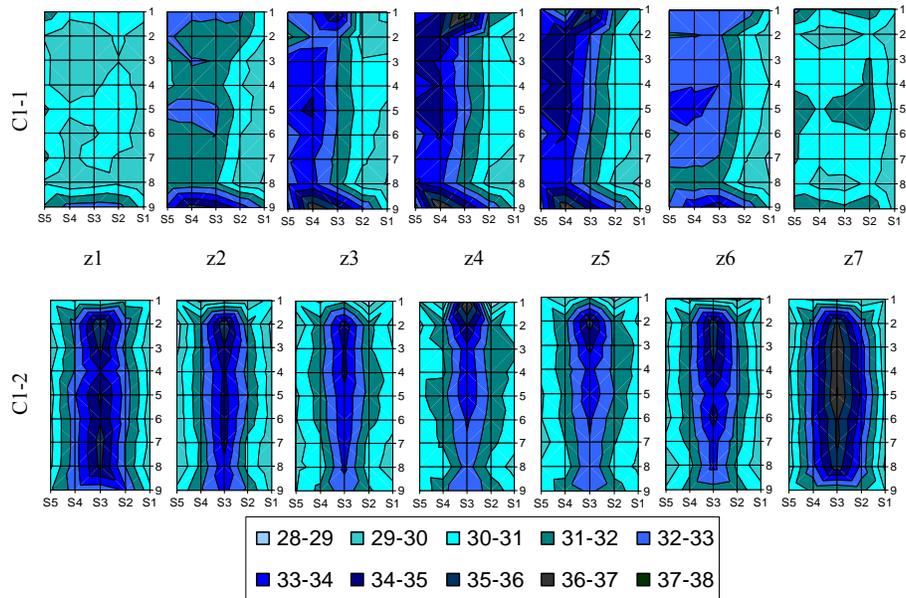


Pic. 2. Compressive strength at 10% deformation for the block C1–1 and C1–2 samples, kPa

Pictures 12 and 13 clearly demonstrate that the applied differing incoming steam flow directions influence the homogeneity of expanded polystyrene product properties in the EPS blocks and they have varied division of mechanical properties in the volume.

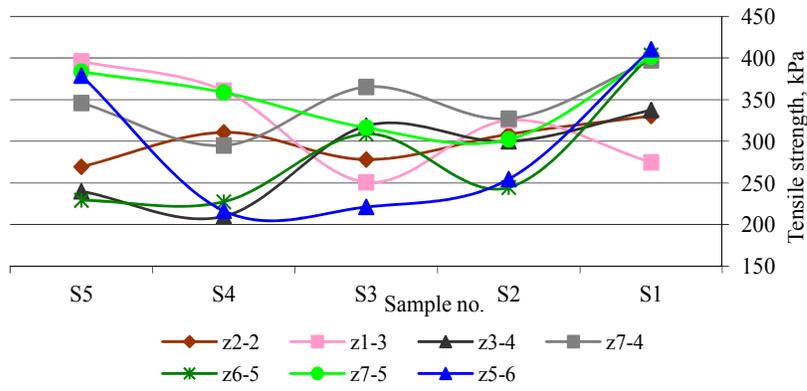
One-way steam feeding (programme P1) causes certain asymmetry in properties – the compressive strength and density for several cuts in the block’s left side are with much higher values than in the right side. However the programme P2 causes more symmetrical parameter division in the volume with higher values in the centre.

It is obvious that there is a correlation between the values of compressive strength and density of the EPS products (Pic. 13). It is noted that by increasing the density proportionally increases also values of the compressive strength.

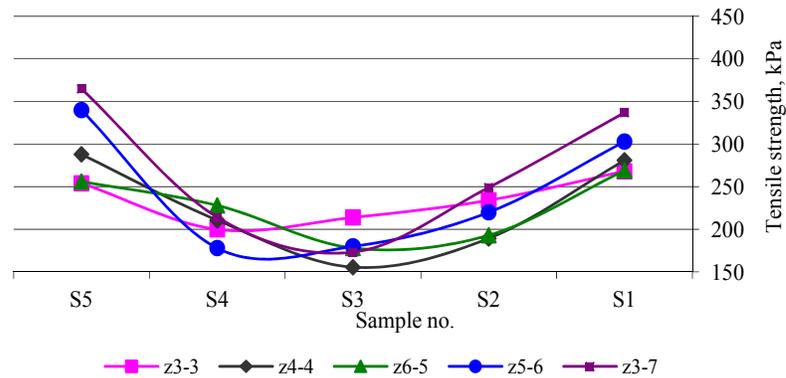


Pic. 13. Density for the block C1 – 1 and C1 – 2 samples, kg/m<sup>3</sup>

Comparing the obtained compressive strength data of different block places for the block C1-1 and block C1-2 (in Pictures 14 and 15), it is clear that in the centre of the block C1-2 they are much lower than on the sides. However for the block C1-1 the property change over slabs is considerably high with a wavy character, there is no significant decrease in the centre. Based on the obtained compressive strength data (Pic. 15) it can be concluded that by using two flows (in the block C1-2) the steam deviates to sides diffusing out of the blockform through the closest exit and does not reach the mould centre, as a result of which the granule fusion in the block centre is very low.



Pic. 14. Tensile strength for the block C1 – 1 samples



Pic. 15. Tensile strength for the block C1 – 2 samples

For the conduction of further research the programme P1 with one exiting flow steam feeding direction was used, as P2 process is more difficult to control and block quality is difficult to predict (very changeable) that has been proved by studies of tensile strength in the centre of block C1-2 ensuring insufficient granule fusion (~170 kPa).

### Influence of the parameter change of the applied vacuum cycle

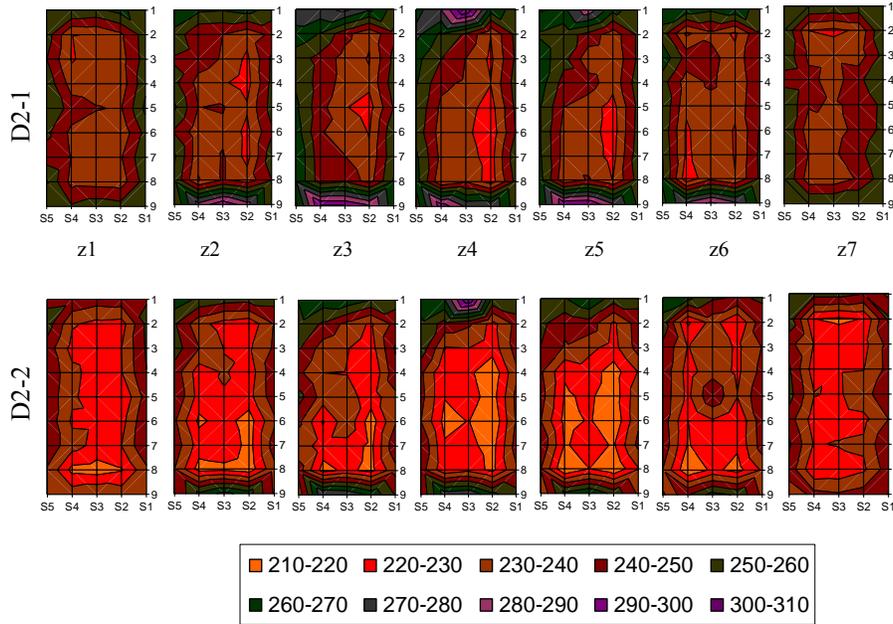
The stage of vacuum is the first stage for block moulding and proceeds in the beginning of moulding when the blockform is already filled with granules. In this stage the excess moisture from the granules, condensate from the heating of the blockform and also a little pentane from the granules are removed.

At block moulding the opening of the main steam valve is kept constant. In the same time it is possible to change the depth of the applied vacuum, besides the regulating system automatically sets the corresponding vacuum time.

The equipment manufacturer recommends the vacuum depth up to 0,65 bar. The applied vacuum for the experimentally prepared block D2-1 is set to 0,55 bar and for D2-2 0,65 bar. The vacuum time for the block D2-2 has proportionally decreased.

With the application of deeper vacuum for the block D2-2 a longer time for reaching atmosphere pressure is necessary in the next stage.

The set product compressive strength at 10% deformation and density in the blocks is reflected in Pictures 16 and 17.

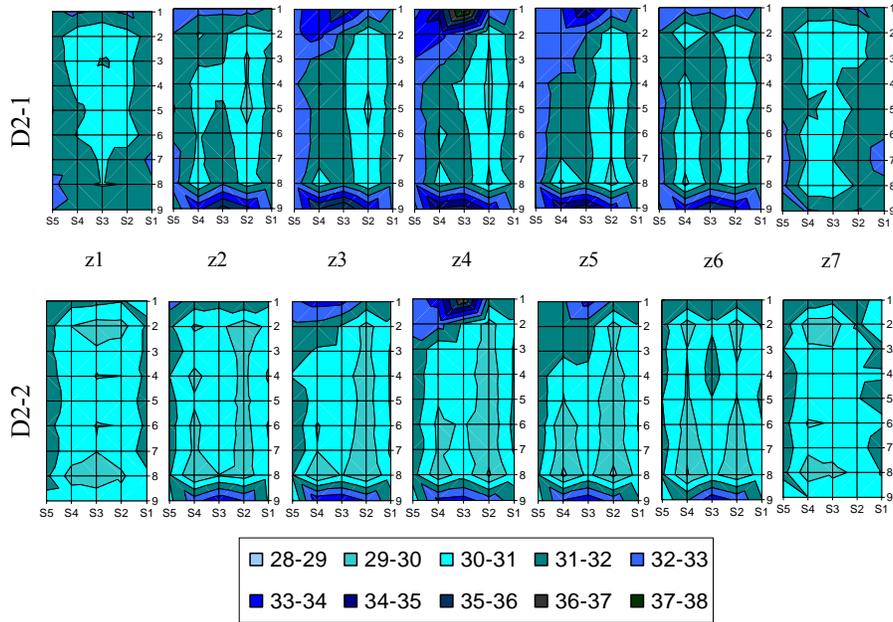


Pic. 16. Compressive strength at 10% deformation for the block D2-1 and D2-2 samples, kPa

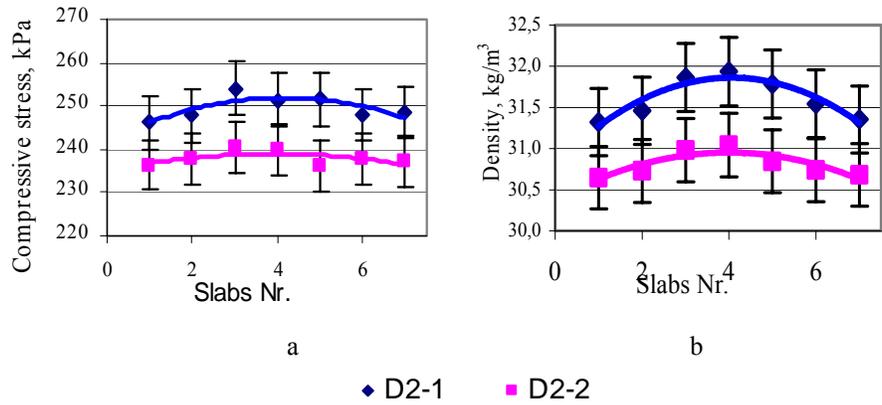
Comparing data of compressive strength and density of slabs z1 and z7 for both blocks it is obvious that colour outlines are similar. It can be explained that these slabs are located by the sides of the block and vacuum influence here is less significant.

Analysing the data of next slabs from z2 to z6 it can be seen that for the block D2-2 the lighter areas in the central part, that correspond to smaller compressive strength (210 – 220 kPa), characterise more effective granule processing with steam

facilitating granule expansion that indicates that application of deeper vacuum has facilitated more intense penetration of steam in deeper layers of the block.



Pic. 17. Density for the block D2-1 and D2-2 samples, kg/m<sup>3</sup>



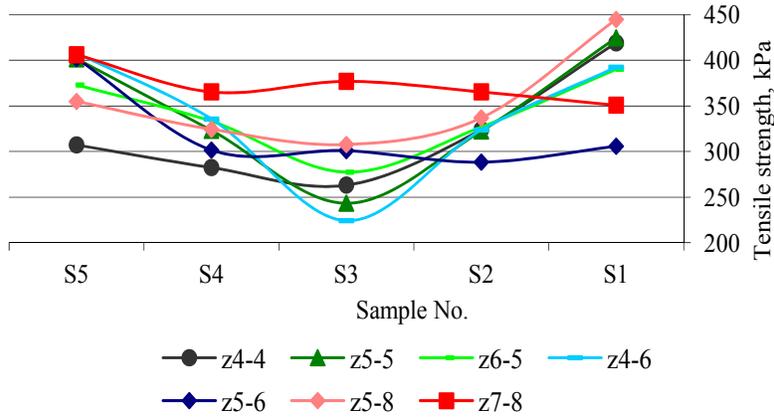
Pic. 18. Comparison of average values of compressive strength (a) and density (b) for the blocks D2-1 and D2-2

**b**

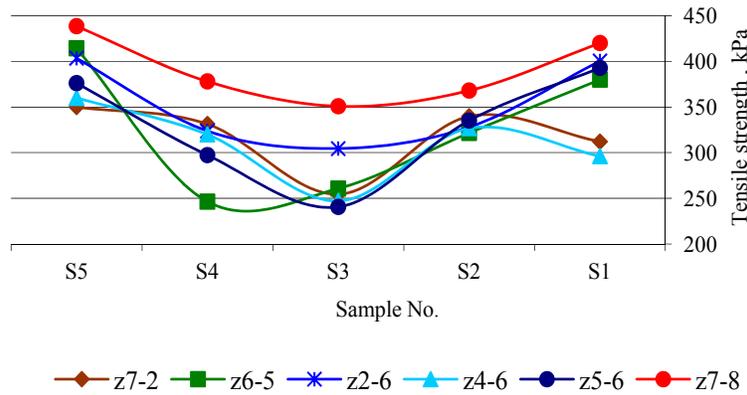
In Picture 18 the average values of the EPS product compressive strength and density have been compared for both blocks by slabs. It can be seen that the block D2-1 values are higher, but for the block D2-2 the value division is more regular.

Thus, 0,65 bar vacuum ensures the decrease of the compressive strength and density and more regular (closer to average) division of the mechanical properties.

In Pictures 19 and 20 the measurement results of tensile strength of the EPS products of both blocks by cuts S are reflected. None of the samples in the whole block has tensile strength less than 230 kPa. Higher values are on the sides of the block that correlates with measurements of compressive strength and density. Despite vacuum parameter changes, the average values of tensile strength for the blocks D2-1 and D2-2 differ only little.



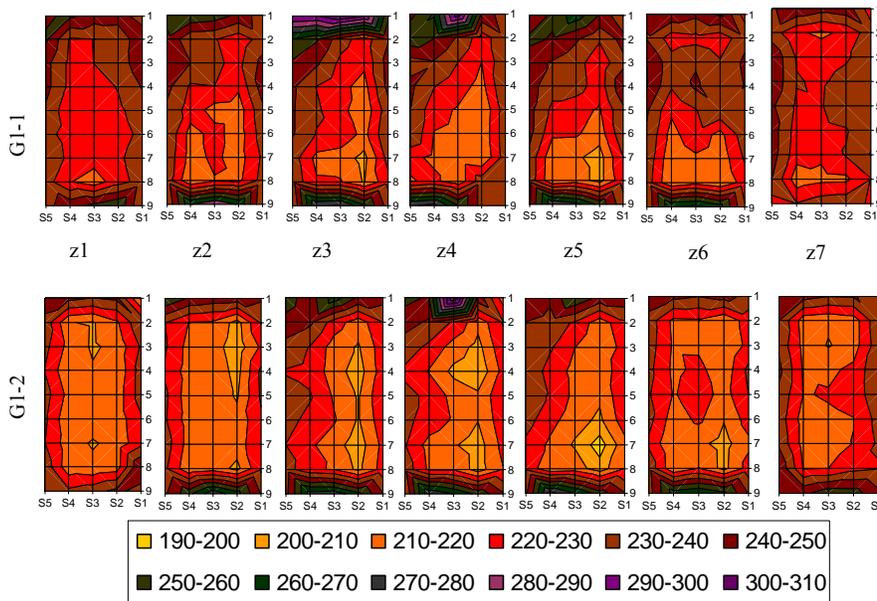
Pic. 19. Tensile strength for the block D2 – 1 samples



Pic. 20. Tensile strength for the block D2 – 2 samples

### Influence of atmosphere pressure reaching stage and primary steaming time

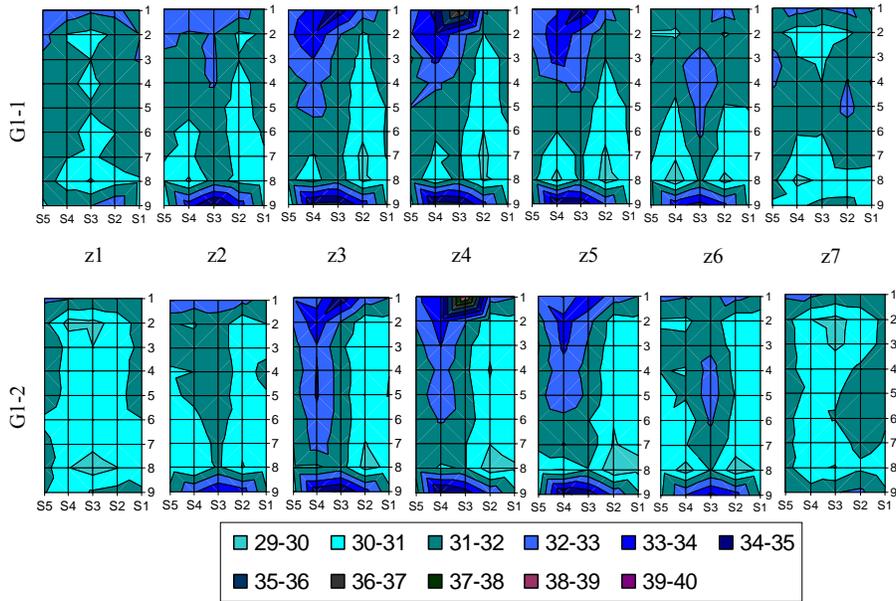
Atmosphere pressure reaching stage and primary steaming are next stages of the moulding process. The aim of these stages is to prepare the granules for ultimate fusion previously warming them up slightly with steam for gradual expansion. The experiments were made with blocks G1-1 and G1-2. The atmosphere pressure reaching stage and the primary steaming stage for the block G1-1 are for 3 seconds longer at equal pressures and flow speeds for both blocks. The obtained data in blocks for the EPS product compressive strength and density are reflected in Pictures 21 and 22.



Pic. 21. Compressive strength at 10% deformation for the blocks G1-1 and G1-2, kPa

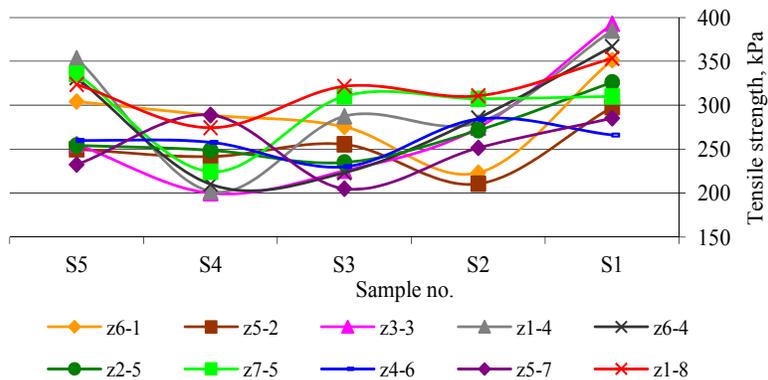
The decrease of stage length changes the division of the mechanical properties in the whole block volume.

In Picture 21 it can be seen that for the block G1-2 by using shorter time period for the duration of stages larger areas of inner outlines were obtained with smaller parameter values (200 – 210 kPa) for the column S4. The block G1-2 has more regular compressive strength division in slabs z1, z2, z6, and z7 compared to the block G1-1. For the block G1-2 by using shorter time period the density in the block side slabs z1 and z7 decreases and also in S2 columns the area of the values 30-31 kg/m<sup>3</sup> increases (Pic. 23).

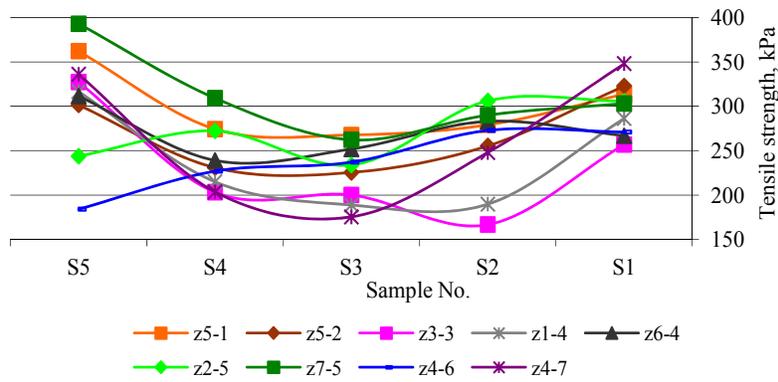


Pic. 22. Density for the blocks G1-1 and G1-2, kg/m<sup>3</sup>

Analysing the obtained data it is obvious that the increase of duration time for the stages of atmosphere pressure reaching and primary steaming at equal steam flow values, the average values of the EPS product density is more regular, but average values of the compressive strength - more diffused.



Pic. 23. Tensile strength for the block G1 – 1 samples



Pic. 24 Tensile strength for the block G1 – 2 samples

Testing the tension of the expanded polystyrene product strength for the blocks G1-1 and G1-2 (Pic. 23 and 24) it was stated that for the block G1-1 expanded polystyrene products higher tension values are in columns S1, however for the block G1-2 samples the highest values are in columns S5. It indicates that the use of longer time period for the reaching of atmosphere pressure and in the primary steaming stage for the block G1-1, where column S1 is the infeed place of steam, the sufficient granule fusion decreases the steam flow movement to the central layers of the block. On the other hand for the block G1-2 the column S5 is at the out-feed and does not hinder the flow through the central granules of the block.

#### Influence of the steam shock

The steam shock stage ensures the ultimate fusion for the central area granules.

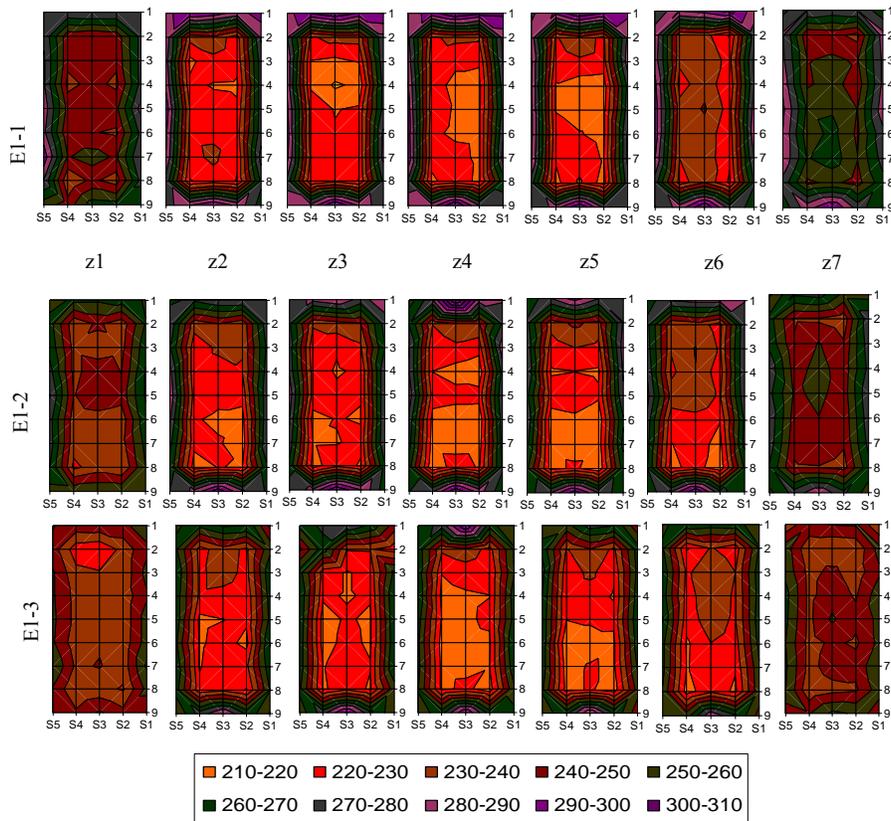
In order to study the influence of steam shock on the EPS product properties in a large-size block 3 blocks were prepared with variable fed steam amount in the steam shock stage within limits of one batch.

In the result of increase of the steam valve opening the time of steam shock shortens according to the action of automatic regulating system. Thus it is not possible to evaluate them (opening percentage and time) each separately, and the valve opening percentage was chosen for the variable parameter. The steam feed valve opening of 37, 40 and 42% were used respectively for the blocks E1-1, E1-2 and E1-3.

The defined compressive strengths at 10% deformation are reflected in Picture 25.

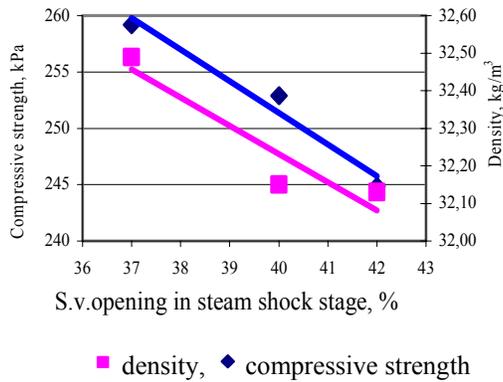
Comparing slabs z1 to z7 from the three blocks it is noted that thicknesses of the outer crust layers that were more pronounced for the block E1 – 1 decrease. It is influenced by slower steam flow feed to the inner block layers using smaller steam valve opening, thus fusing better the granules on the sides. With the increase of the

valve opening percentage in the steam shock stage gradual increase of the central area in the slab z4 is observed (compression value 210- 220 kPa) from the block E1 – 1 to E1 – 3 (Pic. 25).



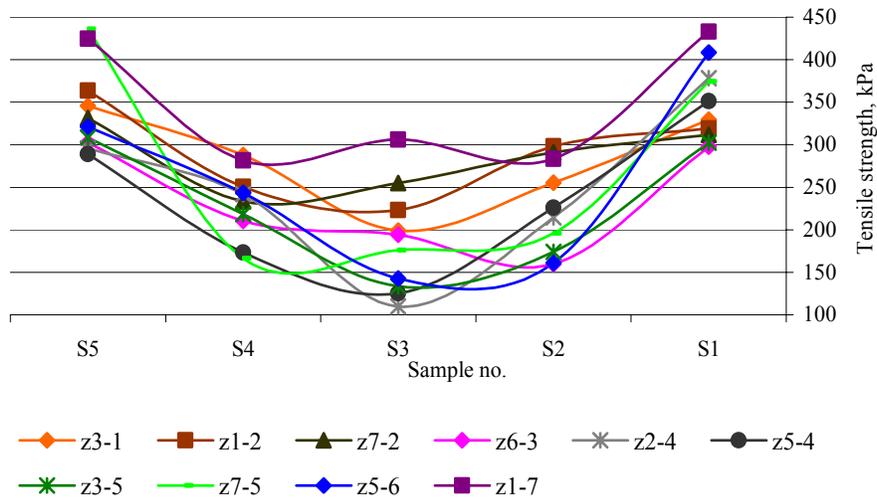
Pic. 25. Compressive strength at 10% deformation for the EPS block D3 E1 – 1; E1 – 2 and E1 – 3 samples, kPa

The increase of the steam shock flow (and simultaneous time decrease) decreases the average values of compressive strength and density in the block that is obviously seen in Pic. 26.

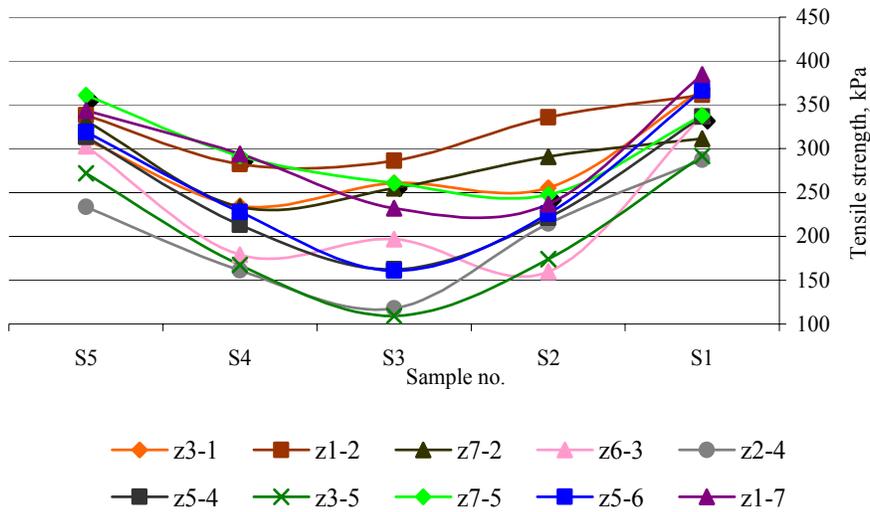


Pic. 26. Dependence of compressive strength and density average values in the blocks from the steam valve opening

Making the EPS product test in tension in the blocks E1-1 and E1-3 (Pic. 27 and 28) it was stated that with a larger steam valve opening (E1-3) the tension values are more regular in the whole block volume. The tension values for the EPS products from the block E1-1 vary between 100 – 450 kPa, while for the block E1-3 EPS products from 100 – 370 kPa. Comparing respective samples of both blocks, for example, z5-4 or z5-6, higher values are showed by the sample in the block E1-3. It confirms once more that by using larger steam valve opening the steam reaches the block centre easier and facilitates more regular granule fusion in the whole volume.



Pic. 27. Tensile strength for the block E1 – 1 samples



Pic. 28. Tensile strength for the block E1 – 3 samples

### Influence of granulometry on block homogeneity

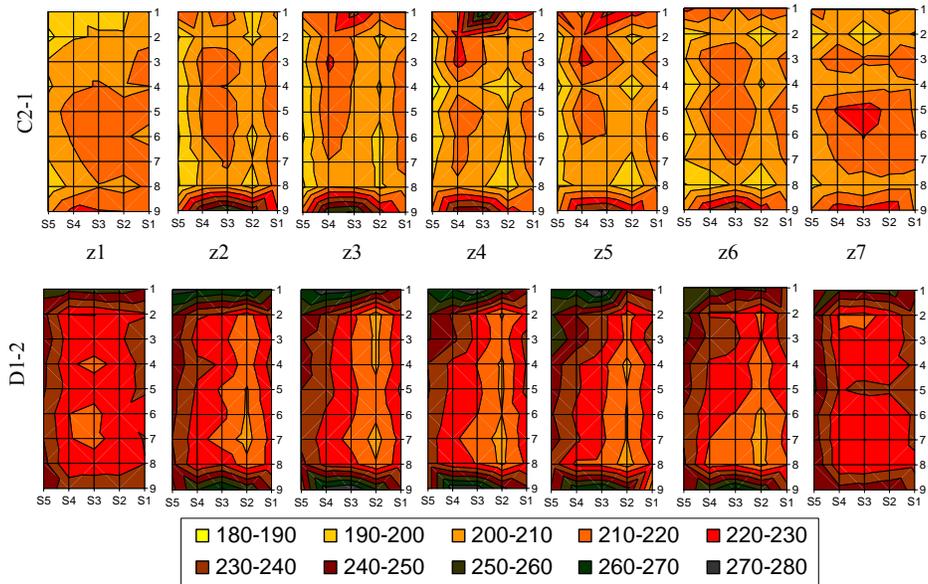
The influence of technological parameters on the structure of products can depend also on pentane content and granulometry of the expanded polystyrene granules the block comparison was performed.

The influence of granulometry on the homogeneity of the EPS product characteristics in the block volume was studied by comparing two blocks with equal moulding parameters. The raw materials C2 and D1 were used that were pre-expanded to equal densities but the difference is that C2 is with smaller average granule diameter and higher pentane content.

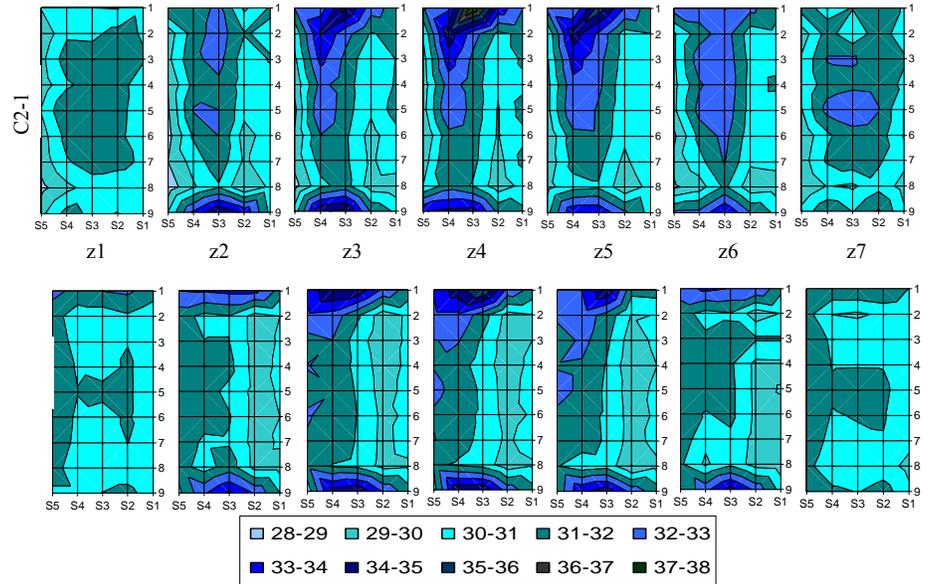
The obtained results for the compressive strength and density are summarised in the graphs (Pic. 29 and 30). The steam flow direction in both blocks was realised according to the programme P1.

In Picture 29 it is seen that for the C2-1 block the values in the column S5 are lower than in the block centre, however for the block D1-2 the values in the column S5 are higher compared to values in the whole block. For both blocks the lowest values are marked in column S2.

In the density graphs (Pic. 30) it was stated that for the block D1-2 the steam has managed to penetrate deeper: in the column S4 compared to the block C2-1 the average density has significantly decreased that proves better granule expansion.



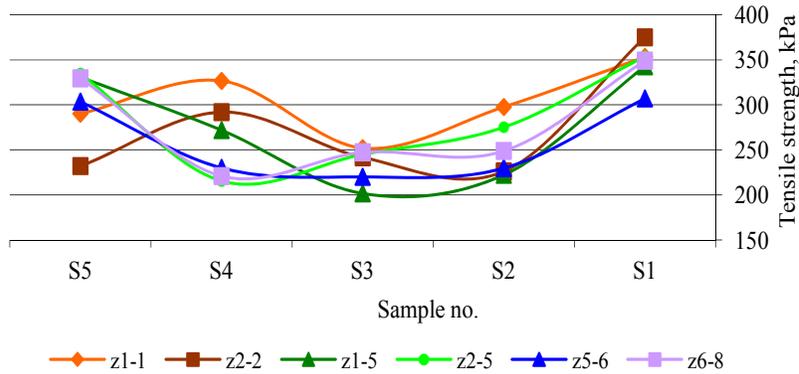
Pic. 29. Compressive strength at 10% deformation for the raw material C2 and D1 EPS block (C2-1 and D1-2) samples, kPa



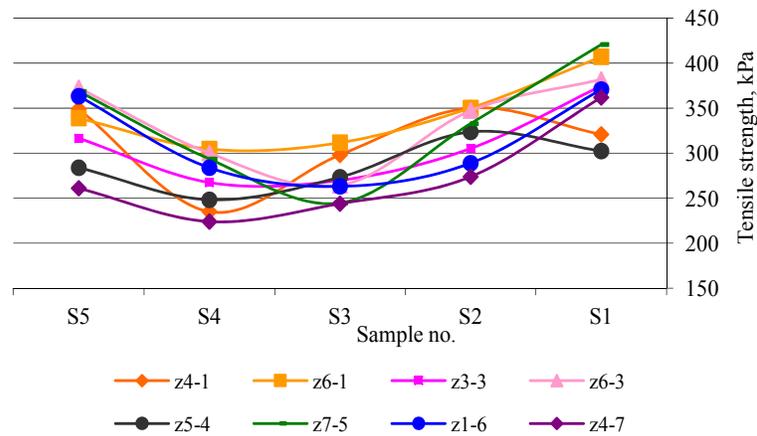
Pic. 30. Density for the raw material C2 and D1 EPS block (C2-1 and D1-2) samples, kg/m<sup>3</sup>

By calculating the average numerical parameter values in the block slabs it was stated that by pre-expanding the granules to the density  $27,5 \text{ kg/m}^3$  in further processing the raw material with larger diameter granules D1 shows higher values in compression, however, the fluctuations of density average values depending on the raw material are insignificant.

By defining the expanded polystyrene tensile strength (Pic. 31 and 32) it was stated that the highest values are showed in the column S1, where the incoming steam flows fuse one block side better, thus decreasing the further flow through the block. However, indices of tensile strength defined in the whole block at these moulding parameters do not significantly differ among the blocks.



Pic. 31. Tensile strength for the block C2 – 1 samples

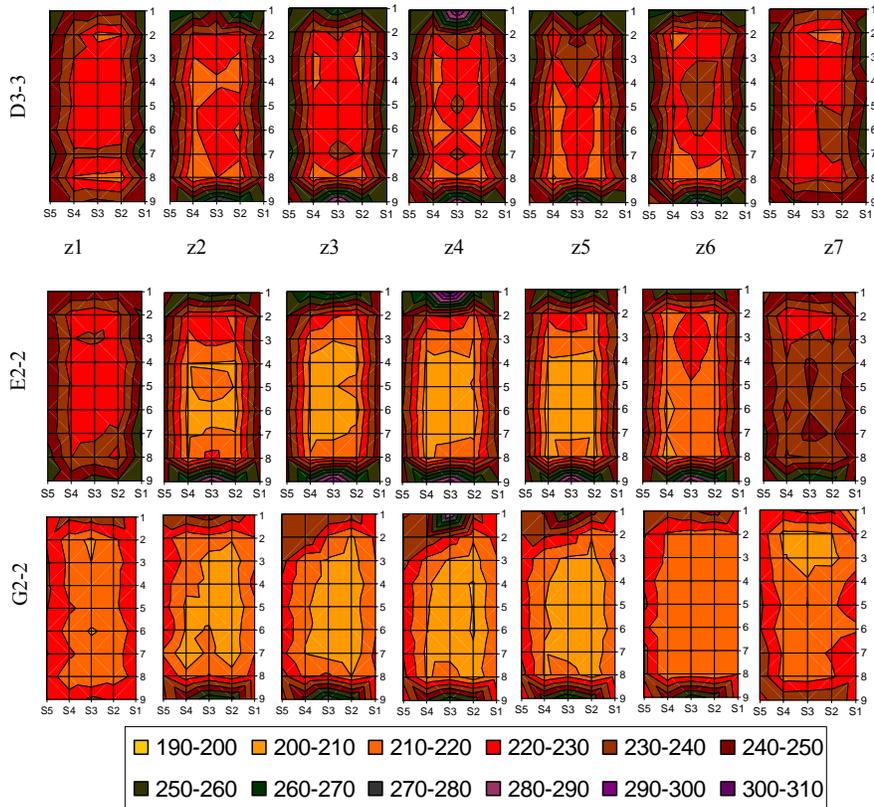


Pic. 32. Tensile strength for the block D1 – 2 samples

Evaluating the influence of the expanded polystyrene granulometry on the product properties it is important to assess the economy of raw material by using granules with diameter that ensures higher mechanical properties at equal densities.

Concluding that the granulometry has influence also on parameter selection in experimental way summarising and evaluating the varying granulometry and pentane content of each raw material the set of parameters for the raw materials D, G and E ensuring the quality of the technological process was developed, given in Table 3, where as comparison former manufacturing parameters are shown.

In Pictures 33 and 34 the mechanical properties of manufactured blocks are showed that were made using the recommended technological parameters according to the expanded polystyrene granulometry and pentane content.

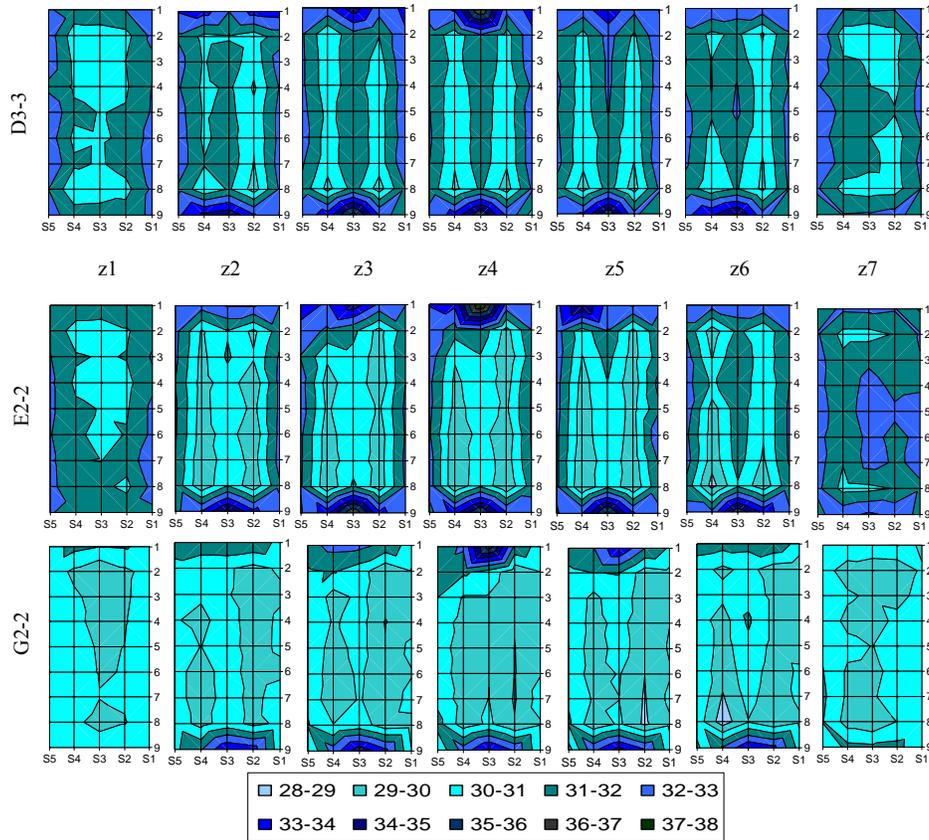


Pic. 33. Compressive strength at 10% deformation for the EPS block D3-3, E2-2 and G2-2 samples, kPa

As it can be seen (Pic. 33) in cases of all three raw materials the value dispersion is lowered. More homogeneous value dispersion of compressive strength in the

block centre has been achieved, as well as a slight symmetry has been obtained between the values in slabs z3, z5.

As the raw materials were pre-expanded to the average densities (D3 – 28,2 kg/m<sup>3</sup>, E2 – 27,7 kg/m<sup>3</sup> un G2 – 27,4 kg/m<sup>3</sup>), then evaluating the graphs of density values (Pic. 34) it can be concluded that in the case of raw materials E and G the pre-expansion density has to be increased to 28 kg/m<sup>3</sup>. It will give conformity to the nominal value. Also in this case the value symmetry in slabs from z2 to z6 has been achieved.



Pic. 34. Density for the EPS block D3-3, E2-2 and G2-2 samples, kg/m<sup>3</sup>

The raw material C during the technological study was admitted to be the most inappropriate for the process realisation in this type of equipment, as despite different applications of the steam parameters it did not ensure the necessary product quality. It could be connected to the high content of pentane and fine granule fraction that cannot fuse evenly in the block form with dimensions 4m x 1m x 1,2m

Table 3

Elaborated recommended technological parameters for the raw materials D, G and E and former manufacturing parameters

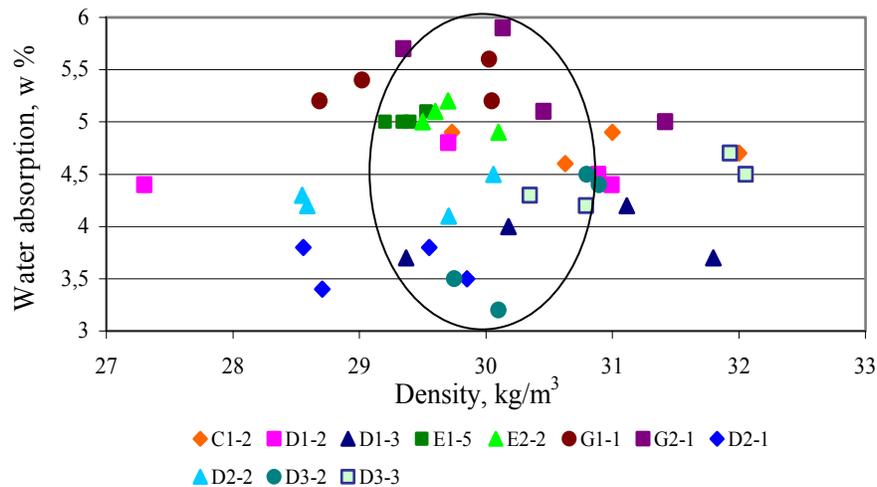
| Parameters /Raw material   |     | <b>D</b>       | <b>G</b>       | <b>E</b>       | <b>Former manufacturing parameters</b> |
|--|-----|----------------|----------------|----------------|--|
| Opening of the steam valve in atmosphere pressure reaching stage | %   | 28 – 30        | 26 – 28        | 26 – 28        | 21 – 24                                |
| Opening of the steam valve in primary steaming stage             | %   | 28 – 30        | 28             | 26 – 28        | 17 – 22                                |
| Opening of the steam valve in steam shock stage                  | %   | 42 – 55        | 42             | 42             | 34 – 37                                |
| Opening of the steam valve in dwell steaming stage               | %   | 9 – 12         | 9 – 12         | 9 – 12         | 9 – 10                                 |
| Granule conditioning   | h   | 24-60 and more | 24-60 and more | 24-60 and more | 24-60 and more                         |
| Applied vacuum   | bar | -0,6           | -0,50 to -0,55 | -0,5 to -0,55  | -0,45 to -0,55                         |
|  | s   | to 20          | to 20          | to 20          | to 20                                  |
| Reaching of atmosphere pressure                                  | s   | 7 – 9          | 8 – 10         | 9 – 10         | 10                                     |
| Primary steaming   | bar | 0,3            | 0,3            | 0,3            | 0,4 – 0,45                             |
|  | s   | 10 – 11,5      | 10 – 11,5      | 10 – 11,5      | 12,5                                   |
| Steam shock  | bar | 0,71           | 0,7            | 0,68 – 0,71    | 0,55 – 0,58                            |
| Dwell steaming   | bar | 0,71           | 0,7            | 0,68           | 0,55 – 0,58                            |
|  | s   | 3 – 5          | 3 – 5          | 3 – 5          | 6 – 8                                  |
| Max reached foam pressure  | bar | 0,9            | 0,9            | 0,89           | 0,78 – 0,83                            |
| Stabilisation  | s   | 300 – 120      | 170 – 110      | 300 – 200      | 200 – 80                               |

### 7. Measurements of the thermal conductivity coefficient

In the Thesis the values of the thermal conductivity coefficient for the products of different raw materials were evaluated, as well as properties within one raw material at different manufacturing regimes. It was clarified that the thermal conductivity coefficient slightly increases when the density increases. It is explained by the influence of granule sizes, thermal conductivity increases by increasing the granule size. The thermal conductivity coefficient changes little, it is within limits for the end-product and it is not the determined parameter for the improvement of the technological process.

### 8. Defining of long-term water absorption

The long-term water absorption was defined for the samples from different blocks that have been manufactured from varied raw material. The obtained data is summarised in Picture 35.



Pic. 35. Long-term water absorption

As it can be seen the water absorption of the material is within limits from 3 to 6 volume %. Reviewing the obtained values in density limits  $30 \pm 0,5 \text{ kg/m}^3$  a certain tendency of water absorption value dependence on the used raw material can be observed that could be connected with the granulometry of expanded polystyrene particles and the subsequent differences in the finished material macrostructure. The water absorption is within the necessary norm limits, it does not cause problems for consumers and is not a decisive factor for the improvement of the manufacturing process.

## CONCLUSIONS

1. For the first time the systematic research on properties and structure of expanded polystyrene products was carried out depending on the influence of the technological process parameters in large-size block manufacturing by using real industrial-scale equipment.
2. The influence of raw material granulometry and raw material properties on the pre-expansion of the expanded polystyrene was defined. In order to reach the declared density of  $30 \text{ kg/m}^3$  it is necessary to pre-expand the granules to  $28 \text{ kg/m}^3$ .
3. It was stated that the homogeneity of expanded polystyrene products in the block volume is most significantly influenced by moulding parameters and their values that depend on raw material granulometry, pentane content in granules, conditioning time of the pre-expanded polystyrene.
4. It was stated that by using one and the same raw material and one and the same technological parameter values within limits that are provided by the automatic control system it is possible to obtain expanded polystyrene products from large-size blocks, where mechanical properties between the blocks differ with a standard deviation for compression strength  $\pm 4 \text{ kPa}$ , for density  $\pm 0,5 \text{ kg/m}^3$ . It proves a stable repeatability of the technological process.
5. The influence of moulding parameters on homogeneity of expanded polystyrene products in large-size blocks was evaluated and it was stated that:
  - a) the homogeneity of properties in the central areas of expanded polystyrene large-size blocks is increased by application of deeper vacuum ( $0,55 - 0,65 \text{ bar}$ ); by application of bigger steam flow in the steam shock stage ( $42\%, 55\%$ ).
  - b) the homogeneity of properties in the centre of the block is decreased by increase of the primary steaming time above  $10 - 11 \text{ sec}$ ;
  - c) the distribution of properties in the outer layers of the block is increased by increase of the dwell steaming time above  $5 \text{ sec}$ .
6. In the result of the research the technological parameters for the raw materials (D, G, E) were optimised for the EPS block moulding in the company SIA "Tenapors". In the result of their implementation more homogeneous areas of mechanical properties in the block centre have increased, the improvement by  $15\%$  of the final product quality has been achieved. Formation of defective products, cracking has been prevented and plate curving has been decreased by  $50\%$ .

## **Approbation of the Thesis:**

### **Main research results have been reflected in the following publications:**

1. Medne O., Dreijers I., Bērziņa L. Analysis of the Reason and Consequence Chart of the Expanded Polystyrene Product Manufacturing Process // Environment.Technology.Resources. Latvia, Rezekne.– 2009. – 50.- 55. pp
2. Medne O., Dreijers I., Bērziņa L., Bērziņa – Cimdiņa L. Research on Heterogeneity of the Expanded Polystyrene Using Raw Materials with Different Granulometry // Proceeding of RTU, Material Science and Applied Chemistry. – 2010. – Vol. 22. – 118. – 121. pp
3. Medne O., Dreijers I., Bērziņa L. Influence of Technological Parameters of Mechanical Properties of Expanded Polystyrene Block// Journal of Engineering and Technology. – 2011. – Vol.1 – 1. – 12. pp.

### **The main results of the research have been presented in the following local and international conferences:**

1. I.Dreijers, O.Medne. Analysis of the Expanded Polystyrene Manufacturing Technology // Riga Technical University 47<sup>th</sup> International Scientific Conference. – Riga, Latvia. – October 12 – 14, 2006.
2. O.Medne, I.Dreijers, V.Vītiņš. Research on the Expanded Polystyrene Block Homogeneity// Riga Technical University 48<sup>th</sup> International Scientific Conference. – Riga, Latvia. – October 11 – 13, 2007
3. O.Medne, I.Dreijers, V.Vitins. Uniformity of expanded polystyrene blocks. XIV-th International Baltic Conference materials Engineering & Baltrib\* 2007. - Riga, Latvia. – October 25 – 26<sup>th</sup>, 2007, - 33. p.
4. O.Medne, I.Dreijers. EPS block homogeneity dependence from raw material granulometry// Baltic Polymer Symposium 2008. – Otepa, Estonia. – May 13 – 16<sup>th</sup>, 2008, - 61 p.
5. O.Medne, I. Dreijer. Mechanical Properties of EPS Blocks: Spatial Distribution and Correlation// Junior Euromat 2008. – Lousanne, Switzerland. – July 14 – 18<sup>th</sup>, 2008, [http://webdb.dgm.de/dgm\\_lit/prg](http://webdb.dgm.de/dgm_lit/prg).
6. O.Medne, I.Dreijer, L.Berzina, L. Berzina – Cimdina. EPS mechanical and structural property correlation from technological process parameters// Riga Technical University 49<sup>th</sup> International Scientific Conference. – Riga, Latvia. – October 13 – 15, 2008.
7. O.Medne, I.Dreijers, L.Bērziņa. Analysis of the Reason and Consequence Chart of the Expanded Polystyrene Product Manufacturing Process // 7<sup>th</sup> International Scientific - Practical Conference – Environment. Technology. Resources. – Rezekne, Latvia. – June 25 – 27, 2009.
8. O.Medne, I.Dreijer, L.Berzina, L.Berzina – Cimdina. In amount of steam flow and direction influence on EPS block homogeneity// Riga Technical University 50<sup>th</sup> International Scientific Conference. – Riga, Latvia. – October 12 – 16, 2009.

9. O.Medne, I.Dreyer, L.Berzina. Research on Quality Improvement of Expanded Polystyrene Blocks Manufacturing// Material Science and Technology. – Darmstadt, Germany. – 24 – 26<sup>th</sup> August , 2010.
10. O.Medne, I.Dreijer, L.Berzina, L.Berzina – Cimdira. Influence of preexpansion conditions of inner structure of expanded polystyrene granules// Riga Technical University 51<sup>st</sup> International Scientific Conference. – Riga, Latvia. – October 11 – 15, 2010.
11. O.Medne, I.Dreijers, L.Bērziņa. Influence of Technological Parameters of Mechanical Properties of Expanded Polystyrene blocks// RISE 2011 Triconto. – Poprad, Slovakia. – 21 – 26<sup>th</sup> June, 2011, <http://www.ijet.eu/ijet/>.

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