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# INVESTIGATIONS OF POLYSTYRENE PRE-EXPANSION PROCESS BY USE OF TEST STAND EQUIPPED WITH BATCH PRE-EXPANDER

# BADANIE PROCESU WSTĘPNEGO SPIENIANIA POLISTYRENU NA STANOWISKU DOŚWIADCZALNYM WYPOSAŻONYM W CYKLICZNĄ SPIENIARKĘ

Technology of polystyrene pre-expansion process by use of test stand equipped with batch pre-expander was displayed. Additionally the test stand is fit out with fluidized bed dryer and silo for aging pre-expanded polystyrene. Studies of pre-expansion process, to determine the effect of the expansion pressure and expansion time on foamed polystyrene granule bulk density , were carried out. Also carried out researches determining influence of drying process and aging time on foamed polystyrene density. Analysis of test results confirmed that with increasing of expansion pressure up to 1,4 bar the bulk density of polystyrene decreases. Similarly, it was found that with increasing expansion time bulk density decreases.

*Keywords*: engineering, lost foam, foamed polystyrene patterns

W pracy przedstawiono technologię wstępnego spieniania polistyrenu na stanowisku badawczym wyposażonym w spieniarkę cykliczną. Stanowisko badawcze wyposażone jest w spieniarkę do pracy cyklicznej, suszarkę fluidyzacyjną oraz silos do sezonowania wstępnie spienionego polistyrenu. Przeprowadzono badania procesu wstępnego spieniania mające na celu określenie wpływu ciśnienia spieniania, czasu spieniania, na gęstość nasypową granulek styropianu. Przeprowadzono również badania mające określić wpływ procesu suszenia i czasu sezonowania na gęstość spienionego styropianu. Analiza wyników badań potwierdziła, że wraz ze wzrostem ciśnienia wstępnego spieniania do ciśnienia 1,4 bar gęstość nasypowa styropianu maleje. Podobnie stwierdzono, że wraz ze wzrostem czasu spieniania gęstość nasypowa maleje.

## 1. Introduction

Such significant interest of cast manufacturing technology by mentioned method is caused by lower, in compare with the traditional process, production costs and investment outlays [2]. As well as, compared with the traditional casting process with use of classical moulding sands, presents numerous advantages:

- the possibility of obtain an inner casting shapes without the use of cores,
- the use of moulding sand without binders (i.e. the use of pure sand), eliminates an expensive process of moulding sand preparation,
- significantly lower production costs,
- reduce the number of fettling operations of castings due to the lack of cores and mould parting planes (lack of flashes),
- reducing the amount of equipment and tooling (no moulding machines and mixers are necessary for the sand preparation, etc. )
- labour consumption reduction of final operation following the lack of flashes, burns-on, etc)

Many factors have an influence on the quality of casts made by this technology for example: density of foamed polystyrene (from which the model strength depends on and quality of its surface); the kind of sand which is base sandmix (in particular its permeability) and refractory cover deposited on the model which is a work area of mould and enable to obtain an appropriate surface quality of cast and prevents metal from penetration of sand grains [2, 3].

The density pattern mainly depends on the bulk density of the pre-expanded polystyrene. In the study was presented pre-expansion station description equipped with batch pre-expander, fluidized-solid dryer, uploading pre-expanded and air-dried beads of foamed polystyrene and preliminary studies carried out in this stand.

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## 2. Analysis of factors determining the pre-expansion process

In order to receive demand density of the expansion polymer carries out the initial foaming. Pre-expansion process of expandable polystyrene beads can be achieved by the heating in boiling water, by steam, high frequency currents and infrared radiation [4]. Most pre-expansion is carried out using only steam heater or in combination with vacuum [5, 6, 7, 8]. The aim is to obtain a foam beads with as minimum as possible bulk density. It should be remembered that with the reduction of the density decrease strength and hardness of foamed polystyrene and get worse surface quality. Expandable polystyrene is saturated of porophor (izopentane) which the evaporating temperature is 28÷30°C. In the process of expanding polystyrene, in evaporation temperature of porophor a pressure inside the beads increases. The result of process of expanding polystyrene is stretching of the wall granules leading to an increase of its volume, from the softening temperature of polystyrene around 80°C. At the appropriate temperature of pre-expansion polystyrene (100÷105°C), followed a rapid growth of beads volume, up to several tens of times.

Fig. 1. Beads of polystyrene before and after pre-expansion process

Beads are dried and cooled after the expansion. Then undergoes to the process of aging-activation. The air diffusion inside granules, by thin walls, during aging proceed. This process occurs because inside the beads occurs a pressure lower than atmospheric as a result of condensation of porophor. With time, steaming porophor diffuses outside the granules and in consequence the mass of beads decreases. These phenomena have a significant impact on activity of beads during the formation of pattern in the matrix.

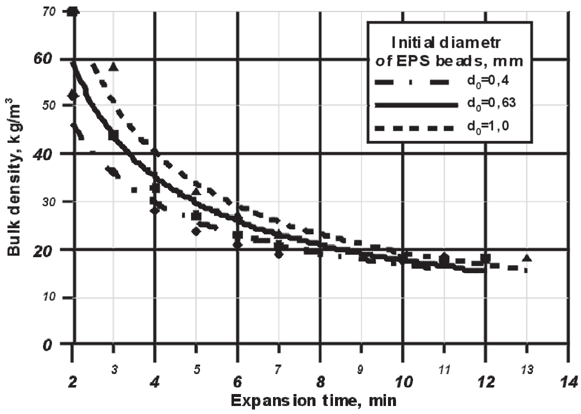


Fig. 2. Dependence of bulk density from the time of expansion and the initial diameter of EPS beads [9]

At the pre-expansion process affects temperature-pressure and time of expansion, amount of porophor, heating rate of beads, the pressure of the surrounding environment. Effect of expansion time on bulk density for different initial diameters of beads is shown in Fig. 2 [9].

## 3. The station of pre-expansion

The comprehensive station of pre-expansion polystyrene presented in this study was designed and constructed by the own research project No. N N508 443536. The station allows to foam polymer material with steam's support. A station is based on the pre-expander SC-500.

### 3.1. Description of the pre-expansion station

Station of pre-expansion shown in Figure 3 consists of: water purification plant Epurosoft ES 37, steam generator LW 40.1 Prometr Co., batch pre-expander SC-500 with fluidized-solids drying plant of Grom Co., connected through a pressure regulator of direct action and silo used of aging pre-expanded beads of polystyrene.

Water purification plant is an ion exchange water softener consists of: a column of fluid known as ion exchange resin, brine tank with a capacity of 25 dm$^3$ and multi-function control head. Carbohydrates, calcium and magnesium dissolved in water, responsible for water hardness are captured in the ion-exchange column of plasticizer during the water flow through the bed. After treatment a certain amount of water, the bed loses its properties. Regeneration by a saturated solution of salt (NaCl) restores the original properties of resin.

All processes of the device run on automatically. The device allows for treatment to 0.8 m$^3$ of water per hour.

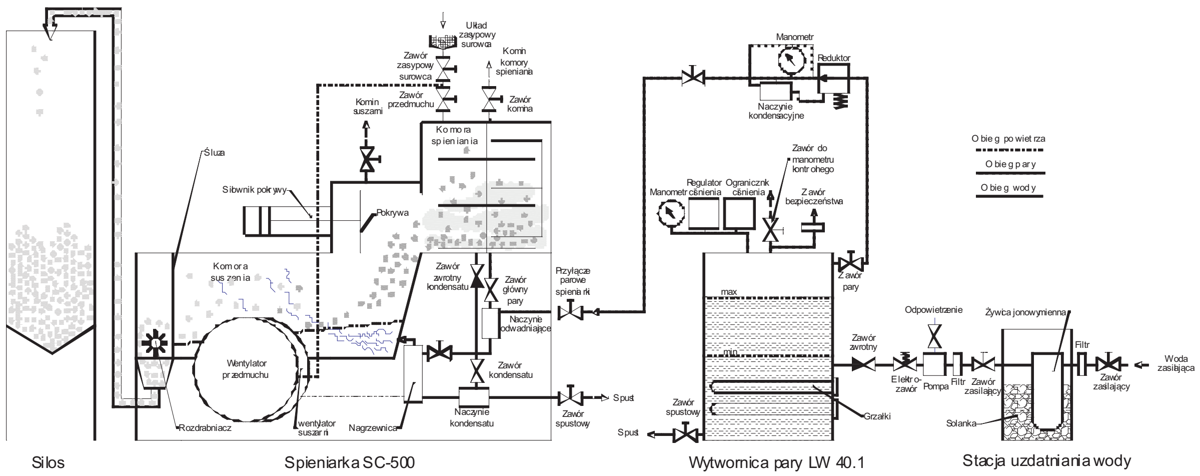


Fig. 3. Scheme station of pre-expansion the polystyrene, equipped with a batch pre-expander. [11]

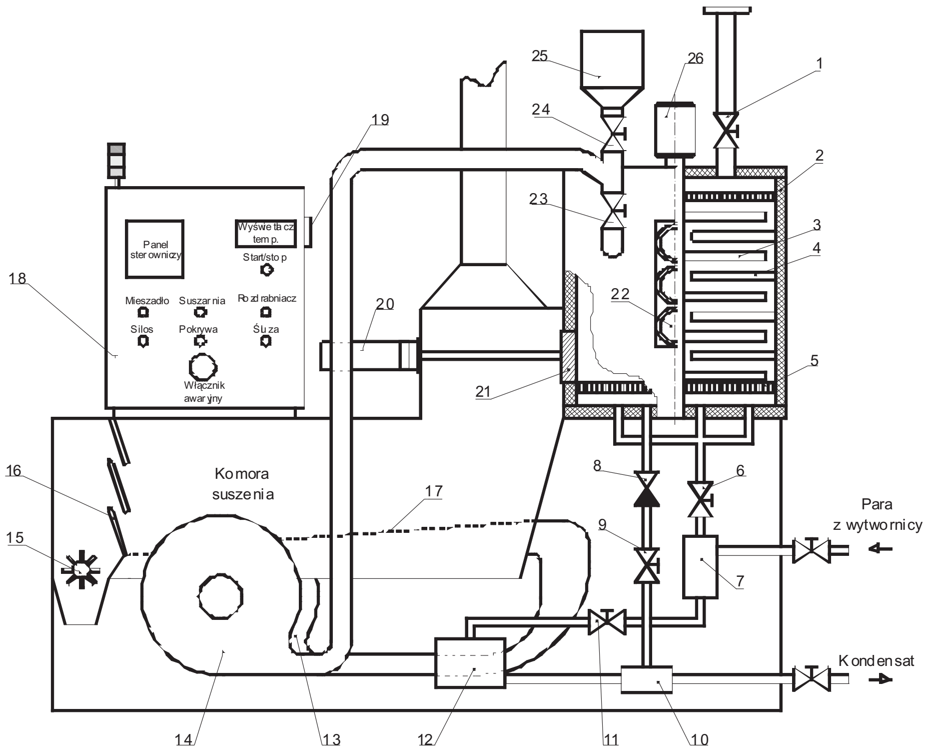


Fig. 4. Scheme a batch pre-expander SC-500 [11] 1 – cut-off valve of the chimney, 2 – chamber of pre-expansion process with thermal insulation, 3 – mixer, 4 – hogging rods, 5 – perforated bottom, 6 – main valve of the steam , 7 – vessel on the drip, 8 – non-return valve of condensate, 9 – valve of condensate, 10 – hot-well, 11 – valve of heater, 12 – steam heater 13 – fan dryer, 14 – blow fan, 15 – crusher, 16 – lock, 17 – perforated bottom of the dryer, 18 – control box, 19 – main switch, 20 – pneumatic actuator cap, 21 – cap dump, 22 – sight-glass, 23 – valve of blow, 24 – valve of charge of raw material, 25 – container on raw material, 26 – electric motor of drive mixer

Steam generator with electric heating is a source of steam. It is equipped with 50 liter water tank, impeller pump and two modules of electric heaters each for heating power 14 kW. It allows to obtain a steam pressure up to 6 bar and has an efficiency to 40 kg of steam per hour.

A batch pre-expander SC-500 shown in Fig. 4 is connected through a pressure regulator to the steam generator. The pre-expander is equipped with insulated chamber (2) with capacity of 90 $cm^3$. At the wall of the chamber is installed sight-glass (22), which allows to observe the expansion process. The pre-expander allows, depending on the parameters of expansion and the kind of raw material, to obtain the bulk density of foamed polystyrene from 15 to 40 $kg/m^3$. Pre-expander control is based on the Mitsubishi programmable controller placed in the control box (18). This makes the process of expansion fully automatically and repeatedly. Automatic cycle proceed as follows. After pressing the start button on the control box mixer rotation begins (3) driven by an electric motor (26). The flap value of charge of raw material opens (24) and expandable polystyrene EPS located in a container on raw material (25) is taken out to the expansion chamber by a pneumatic nozzle. Then the flap valve of charge of raw material is closed (24), the valve of the chimney (1) valve of condensate (9) and the main steam valve is open (6). Steam is supplied by inflow of the branched into three channels to the chamber at the bottom of the slot (5). Then moves to the right chamber. This solution is designed to obtain uniform stream of steam. Expansion chamber filled up with steam to set value pressure. Then followed blow steam for a limited time and at a given pressure. Alternately opens and closes the valve chimney and steam. After the evaporation phase the main steam valve closes and opens the valve chamber. This causes pressure reduction to atmospheric in expansion chamber. Ventilation phase begins – accompanied by a blow fan and blow-condensate valve open. Ventilation of the chamber finishing cycle of expansion. Pneumatic cylinder (20) opens the cap dump (21) and polystyrene beads are transported to the drying chamber. Then cap dump is closed and turn on the dryer fan. Air passes through the water heater (12) and is given at the perforated bottom of the dryer (17). Then fluidized bed drying of polystyrene beads occurs. After the drying cycle lock is opened (16) and runs the crusher (15), whose task is to break glued pieces of foamed polystyrene. Beads are transported to the silo by air.

## 3.2. The initial process of pre- expansion of foamed polystyrene – preliminary studies

### 3.2.1. Materials and scope of studies

The study included analysis of the bulk density after expansion polystyrene, depending on two parameters, expansion - and time pressure. Expansion time and pressure change from 20 to 180 s, and in the range 1.15÷1.40 bar respectively.

To test was used BASF's expandable polystyrene – STYROPOR F 495 containing up to 3.8% pentane, isopentane to 0.9. Bulk density of expandable polystyrene was 600 kg/m$^3$, and the diameter of the granules contained in the range 0.3÷0.7 mm. For all studies measured 500 g of raw material.

The study was carried out on pre-expander heated to the temperature of 85°C. The parameters of individual phases in automatic cycle were:

- charge of raw material time – 10 s,
- time and pressure expansion – variables,
- ventilation time – 20 s,
- dump material time – 10 s,
- drying time – 300 s.

Bulk density of foamed polystyrene was determined after 30 min. of aging. Seasoned granules sieved through a sieve of mesh size much larger than the diameter of the granules. This was to capture glued foamed polystyrene beads. The screened granules were poured into a container with a capacity of 2.5 dm$^3$ where was subjected under vibration and then weighed on the scale of the laboratory with an accuracy of ±0.02 g. Based on data of weight and volume was calculated bulk density of polystyrene in the test.

### 3.2.2. Analysis and results of preliminary tests

Figure 5 presents the effect of expansion time on the bulk density of foamed polystyrene at constant pressure P = 1.15 bar, which corresponds to a temperature of 103°C steam. Data shows that the bulk density of foamed polystyrene significantly depend on the time. With increasing expansion time the density decreases. For example, for the time t = 60 s bulk density reaches a value about ρ = 28.5 kg/m$^3$. For expansion times above 40 s the influence of time to change the density is getting smaller. The lowest density of 27.6 g/cm$^3$ rate of polystyrene was obtained for the longest time foaming – 180 s.

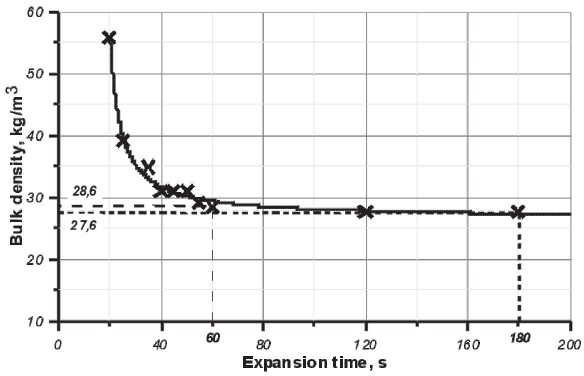


Fig. 5. Influence expansion time on the density of foamed polystyrene at constant pressure P=1.15 bar

Effect of expansion pressure on bulk density of polystyrene is shown in Fig. 6. The study was conducted for a permanent time expansion t = 180 s, because of the lowest density of foamed polystyrene received. The data is presented in graphical form in Figure 6. From these data reveal that it is possible to obtain a foamed polystyrene declining density with increasing pressure. For maximum test expansion pressure P = 1.4 bar (the temperature of the steam is T = 109°C), the density of polystyrene was obtained ρ = 17,6 kg/m$^3$.

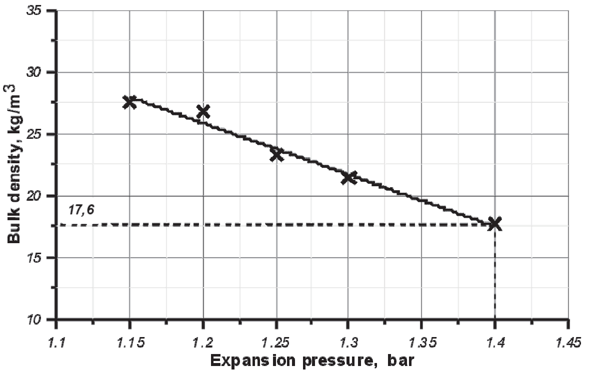


Fig. 6. Influence expansion pressure on the density of foamed polystyrene at constant time t=180 s

Figure 7 compares the results of density polystyrene depending on expansion time and pressure. Dotted line shows the trend line (curve fitting) which is a rational function of the form:

$$\rho(t) = \frac{A}{C \cdot t - D} + B \tag{1}$$

where: A, B, C and D are coefficients calculated using the least sum of squares. For example, for pressure p = 1.15 bar (Fig. 7a) these factors are A=22.154, B=26.647, C=0.181, D=-2.864 and are various for different foaming pressures. Determination coefficient $R^2$ which is a measure of the quality of the fit of the model for these curves falls in the range of 0.945 to 0.991.

Analysis of the results obtained from experiments allowed to elaborate the dependence between time and pressure influence on polystyrene bulk density:

$$\rho(t,p) = \frac{-9493 \cdot p^2 + 23998 \cdot p - 14854}{0,9 \cdot p \cdot t - 17} + \frac{30}{p^p} \tag{2}$$

The relationship described by equation (2) is shown in Fig. 7 by solid line. Fitting functions to experimental data is proper as evidenced by the coefficient of determination R2 over 0.9. Only for pressure p = 1.2 bar, it takes the value of 0.852.

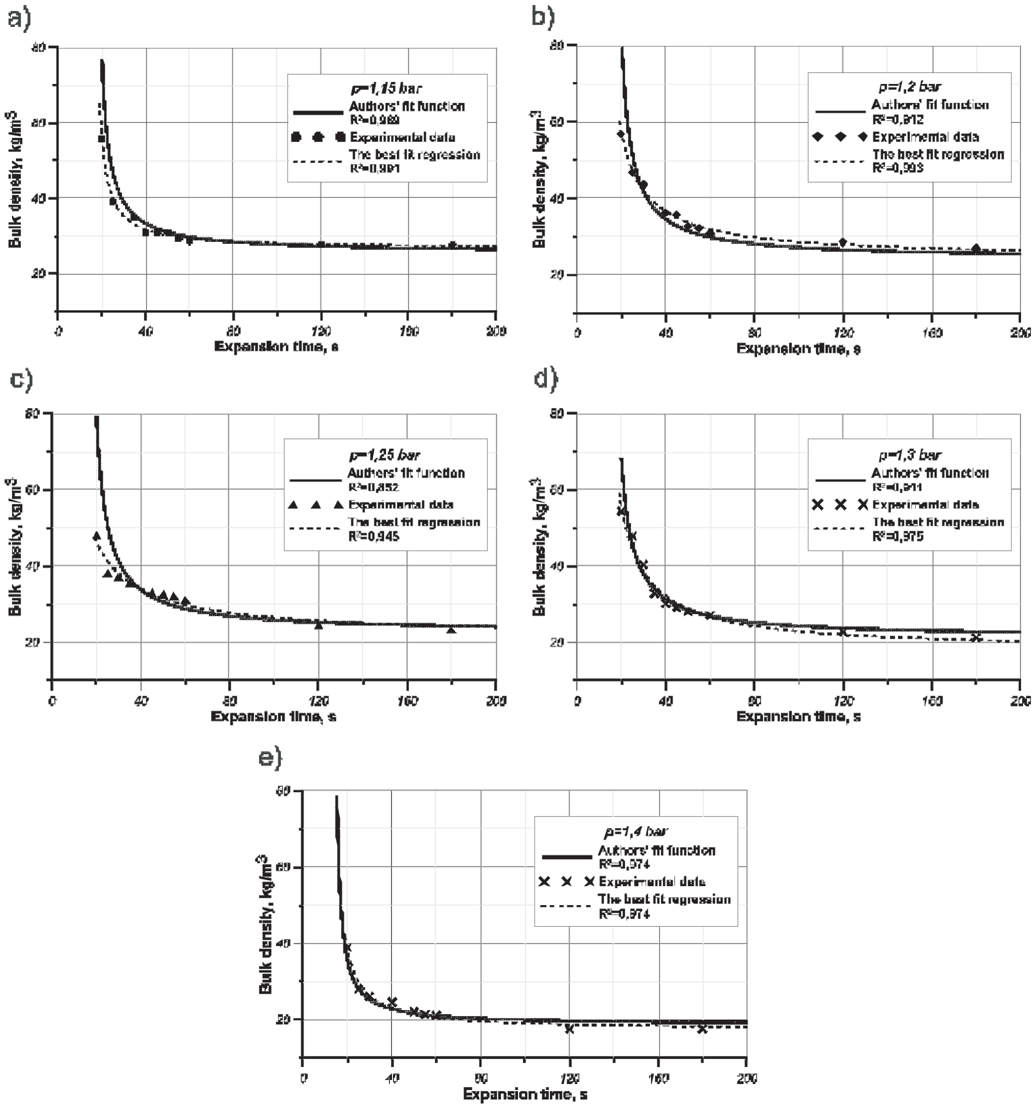


Fig. 7. Effect of expansion time and pressure on the bulk density of foamed polystyrene

It is known that immediately after expansion as a result of sudden cooling of granules followed by condensation of pentane inside the granules, which causes a overpressure inside them. This causes the collapse of granules. It shows in the form of wrinkled surfaces. Therefore, in the preliminary study was examined the surface of polystyrene beads immediately after expansion and 30 minutes later. In studies were not observed this phenomenon. In Fig. 8, polystyrene beads are presented immediately after expansion. The surface of the granules are smooth and their shape is spherical.

Fig. 8. Beads immediately after expansion, magnification x20

## 4. Summary

Preliminary work presented about the initial process foaming test allow to determine the effect of basic parameters – time and pressure – on the bulk density of foamed polystyrene. Studies have shown that with increasing pressure decreases the bulk density of polystyrene. Through the appropriate choice of time and pressure during the expansion process can be obtained in the wide range of density of polystyrene from 17 to 50 kg/m$^3$.

The study also determined the function matches as a variable time and pre-expansion process pressure allowing for the assign of bulk density of polystyrene depending on these two parameters. Coefficient of determination $R^2$ for this function is higher than 0.9, which proves a good match of model to experimental data.

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