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The Aging Time Effects of the Pre-expanded Polystyrene on the Patterns Mechanical Properties

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Abstract

The aging granulate is to activate the blowing agent during the manufacturing process to granulate models can re-expand and shape the model of well-sintered granules, smooth surface and a suitable mechanical strength.
The article presents the results of studies which aim was to determine the optimum time for aging pre-foamed granules for pre-selected raw materials.
The testing samples were shaped in an autoclave, with constant parameters sintering time and temperature. Samples were made at 30 minute intervals. Models have been subjected to flexural strength and hardness.

Keywords: Innovative technologies and casting materials, Foundry, Lost foam, Models of polystyrene, Castings

1. Introduction

The main factors influencing the mechanical properties of the polystyrene model used for Lost Foam Technology are: the density of the model and the parameters of the shape pattern. An equally important issue is the time of activation of pre-foamed granules. The aging is necessary due to the replacement of pairs blowing agent by air, but if you wait too long aging there is a risk of blowing agent to reduce the content of such amount, in which there will be no further expansion. This can cause a lower effectiveness patterns shaping during the final shaping time [1]. Proper selection of the raw material of aging time allows to activate the blowing agent and in the consequences better sintering the granules in the final shaping process, raising the strength properties of the pattern and improved edge reproduction.

2. Technological base of pattern shaping process

For the manufacture of patterns for Lost Foam Technology can use expandable polymers: polystyrene (EPS), polymethyl methacrylate (PMMA), polyethylene (PE), polypropylene (PP) and polycarbonate (PC). However due to the low price and the dimensional stability the most commonly used material is expanded polystyrene, also known as Styrofoam.

For manufacture castings with high accuracy and low surface roughness, material on these patterns should provide:

- appropriate pattern density,
- a good quality surface of the pattern,
- dimensional stability of pattern,
- high mechanical strength,
- the appropriate rate of gasification,

- low price [2]

The manufacturing of pattern shaping process by expandable macromolecular materials can be divided into two stages. The first is the pre-expansion process during which the expandable polystyrene granules are subjected to heat pre-treatment, drying and activation.

The second step is a final shaping process consisting of filling the metal matrix of pre-expanded granules and re-heating of the granules contained in the matrix mapping the shape of the finished pattern. The finished pattern is removed from the matrix after prior cooling.

In the quest to obtain a predetermined density patterns, good surface quality and adequate hardness and bending strength, parameters of the process such as: pre-expansion (time and temperature of the pre-expansion process), the aging and the final shaping process (time and temperature of the sintering) should be very carefully selected.

2.1. The pre-expansion proces

Pre-expansion is carried out to obtain a given density of the foamed polymer. Several methods are known for the pre-expansion process of polystyrene:

- a steam heating,
- heating in boiling water,
- heating with high frequency,
- infrared heating [2] .

Pre-expansion process is most often realized by steam [2].

Expandable polystyrene is saturated with the blowing agent (pentane), which evaporation temperature is about 28÷30 °C. In the process of expanding polystyrene the vaporization temperature of blowing agent, the pressure increases inside the granules as a result of which (starting from the polystyrene softening temperature – about 80 ° C) followed by stretching the wall of the granules leading to an increase in its volume. The water vapor wets the walls of the granules, so that they are more flexible. In the temperature of pre-expanded polystyrene (100÷105 °C) is a rapid increase of the granules volume, up to a few dozen times. After completion of pre-expansion process, the granules are dried, cooled, and subjected to aging-activation. During the aging occurs diffusion of atmospheric air into the inside granules through the thin walls. This process takes place, because the pressure inside of the granules is lower than atmospheric, it is the result of condensation of the blowing agent. Over time the blowing agent diffuses outside the granules and consequently weight of the granules is reduced. These phenomena have a significant effect on the activity granules during the final shaping process of pattern in the matrix. [3].

2.2. The final shaping process

The manufacture of patterns is taken place in a specially-designed matrixes, most often made of aluminum or its alloys. Due to the specifics of the process, the choice of material used to produce matrix is dictated by the high thermal conductivity for aluminum ratio is $\lambda \approx 175 W/m^2K$ [4].

After placing the pre-expanded granules into the matrix they are heating them using the steam. In the final shaping process the blowing agent is re-evaporated, which results in an increase of volume and pressure. The pressure of the granules on the matrix walls significantly increase, the granules contributes to their combination, and in the higher temperature (100÷110 °C) they are sintering [2]. The final shaping process can be carried out by warming the granules from the matrix, or an additional directly vapor-permeable by the pattern. After the final shaping process the matrix with the therein contained pattern are cool, and the consequent is vitrification of plastic (polystyrene) and the condensation of the blowing agent. When the pattern is cooled, they are removed them from the matrix, and then aging them to increase the dimensional stability and flexural strength.

The patterns density depends mainly of the bulk density of pre-expanded polystyrene and the patterns density is on average 20% higher than the bulk density of pre-expanded polystyrene. This is related to the better compaction the granules into the matrix [4].

3. Test benches

3.1. Description of the workstation for pre-expansion

The device GROM SC 500 includes the following modules: steam generator, cyclic blowing machine, dryer, control cabinet and tank for aging pre-expanded polystyrene. In order to ensure the stability of the parameters the expansion chamber should be heated to a temperature of 85 °C. After the pre-expansion process granules are poured into a fluid bed dryer and dried for 300 sec. The dried granulate is pneumatically transported to the tank and aged. The scheme of pre-expansion workstation is shown at Figure 1.

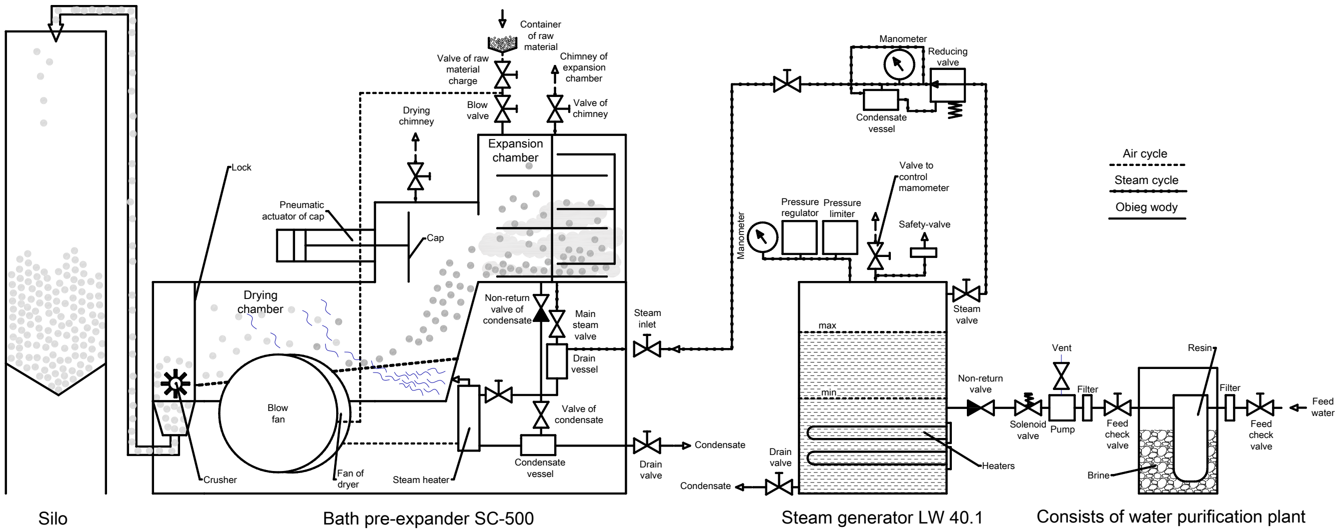

Fig. 1. Scheme station of polystyrene pre-expansion, equipped with a batch pre-expander [5]

3.2. Description of the final shaping process workstation

For the final shaping process the laboratory equipment autoclave GROM A-600 has been used. It consists of the following modules: the steam generator, control cabinet and autoclave. Every time before the process begins the chamber of autoclave was being heated at a temperature of 90 °C. Scheme of the final shaping process workstation is shown in Figure 2.

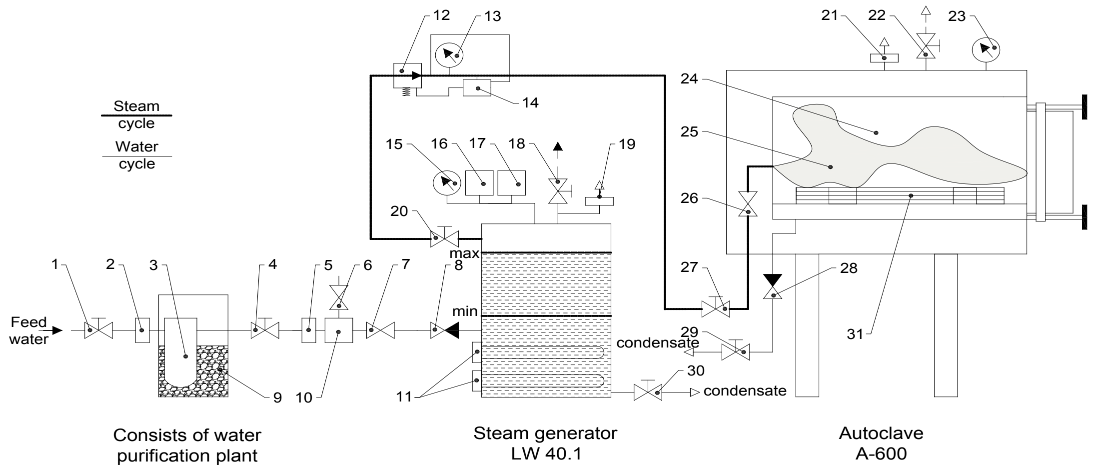

Fig. 2. Scheme of final forming position [6]

1 – feed check valve, 2 – filter, 3 – resin, 4 – feed check valve, 5 – filter, 6 – vent , 7 – solenoid valve, 8 – non-return valve, 9 – brine, 10 – pump, 11 – heaters, 12 – reducing valve, 13 – manometer, 14 – condensate vessel, 15 – manometer, 16 – pressure limiter, 17 – pressure regulator, 18 – valve to control manometer, 19 – safety-valve, 20 – steam valve, 21 – safety-valve, 22 – valve of chimney, 23 – manometer, 24 - shaping chamber, 25 – steam, 26 – steam valve, 27- steam inlet, 28 - non-return valve of condensate, 29 – drain valve, 30 - drain valve, 31 – die

3.3. Description of the test matrix

In the final shaping process the matrixes from aluminum alloy has been used. The matrix has got a special venting plugs. Their purpose is to vent the mold cavity (of the matrix) during filling the matrix with the polystyrene granules and to obtain proper penetration of the matrix by steam.

The matrix with dimensions 30x30x300 has been used to determine samples for bending strength tests. This matrix is presented in Figure 3.

3.4. Description of the workstation for filling the matrix

The Figure 4 shows the scheme of the workstation which was being used in filling the matrix process.

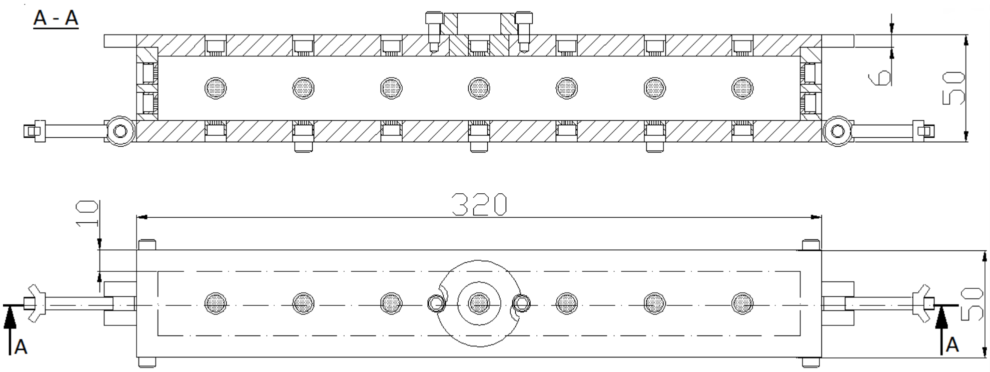

Fig. 3. Scheme of the matrix to prepare the samples for bending strength testing [7]

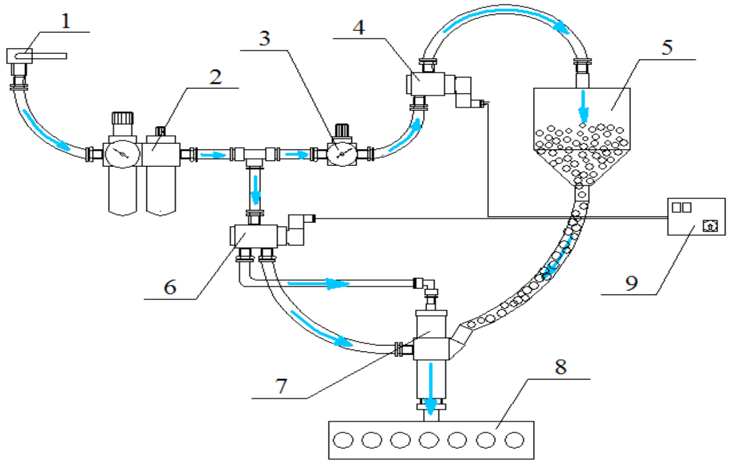

Fig. 4. The scheme of the workstation for filling the matrix witch pre-expanded granules [7]
1- the compressed air valve, 2- block air preparation, 3- reducing valve, 4- separating solenoid valve 3/2 (3-road, 2- positional), 5- pressure tank into granules, 6- separating solenoid valve 5/2 (5- road, 2- positional), 7- filler to the granulate, 8- matrix, 9- console.

4. Own researches

4.1. Scope, purpose and research materials

Studies were performed to determine the optimal time for aging pre-expanded granules for selected raw materials. Two materials were taken under consideration, both with similar bulk density:

- the D933B pre-expanded for 90 sec at 109.0 °C (1,4 bar); bulk density was obtained 22.7 kg/m^3,
- the D833B pre-expanded for 40 sec at 107,9 0°C (1,35 bar); bulk density was obtained 22,5 kg/m^3.

Next both types of granulate was poured into the tank separately. Since then at intervals of 30 minutes suitable quantity of the material has been taken to fulfill the matrix and sintered (from the time of pre-expanded raw material infeed to the tank, until the granules have become sintered together). Patterns were sintered in the autoclave during the time: t_s=90 sec at temperatures: τ_s=121,3°C (2,1 bar). The patterns were tested for bending strength.
Also the impact of aging time on the hardness of the pattern was investigated. The patterns were tested on the analog hardness tester.

4.2. The workstation for testing bending strength

A workstation (shown in Figure 5), equipped with a device TS-1, is designed for determining the mechanical properties of the macromolecular expanded materials. This position allows to determine the bending strength, squeezing and tensile strength.

This paper presents the bending strength tests of expanded polystyrene specimens according to PN-EN 12089:2000.

Fig. 5. The workstation for bending strength testing [8]

4.3. The workstation for testing hardness of samples

Hardness is the property of material which refers to the material's resistance to permanent deformation, caused by local load operation focused on a small area. The hardness of material can be measured by Shore`s method. In this method the material hardness is given by quotient of the balls load and contact area (caused by the ball after certain time). The depth of the impression is measured under load. The surface of the ballprint is calculated from the depth.

The device for measuring hardness by Shore`s method consists of:

- frame with adjustable anvil sample support,
- indenter (the ball) with a matching tip,
- device which allows using the load in a smooth manner.

Fig.6. The device for measuring hardness by Shore`a metod [9]

The device, shown in Figure 6 is equipped with a apparatus for measuring the depth of the impression with an accuracy in the range of 0.01 mm to 10 mm. Indenter is made of hardened steel with a polished surface with a diameter of 5 mm ± 0.05.

4.4. The research methodology

To prepare the samples a specially prepared matrix was used. It is shown in the Figure 3. From ready-made patterns samples with dimensions of 150x28x22 were prepared. They were further subjected to bending strength. Scheme of the strength tests is shown in Figure 4

Bending strength was calculated from the formula:

$$R_g = \frac{M_g}{W_x} = \frac{3Fl}{2bh^2}$$

where,

R$_g$ – bending strength, [Pa]
M$_{gmax}$ – bending moment, [N·m]
W$_x$ - indicator of full rectangular section in bending, [m^3]
F - breaking load, [N]
b - the width of the test sample, [m]
h – the thickness of the test sample, [m]
l - the length of the test sample, [m]
l - the distance between the support rollers, [m].

The hardness of the samples was read from an analog device for testing hardness by Shore`a method.

5. Analysis of test results

Table 1 shows exemplary results of bending strength measurements obtained during tests on the device TS-1 for the various aging times for the pre-expanded granules made from raw samples D933B and D833B sintering with constant parameters described in section 4.1.

Table 1.
Exemplary results of the measurements bending strength of samples obtained during tests on the device TS 1 for different times pre-foamed seasoning granules

Aging times, [min]	Bending strength R_g, [kPa]	
	D933B	**D833B**
0	79	348
30	125	402
60	98	351
90	170	197
120	184	153
150	197	89
180	242	36
210	296	
240	377	
270	405	
300	329	
330	166	
360	152	
390	108	
420	88	
450	102	
480	64	
510	47	

Effect of aging time of pre-expanded granules for the bending strength of patterns (for selected materials) is shown in Figure 7. The presented data shows that the bending strength depends on the time of aging pre-expanded granules. It can be seen that the aging time of pre-expanded polystyrene D933B should be between 200 to 330 min. At the aging time of approx. 270 min provides the maximal bending strength. The aging time of expandable polystyrene D833B should be between 0 to 60 min. At approx. 30 min of aging the samples obtained the maximum bending strength. Exceeding the recommended aging times of aging can result in the bending strength decrease. This is related to the diffusion of blowing agent from the granule.

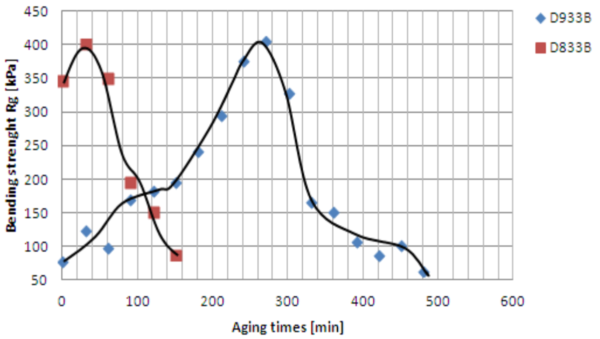

Fig. 7. Effect of aging time on the pre-expanded raw material for the bending strength polystyrene patterns

Table 2 shows examples of the hardness measurements results made for different aging times of pre-expanded granules for the samples raw materials D933B and D833B. They had been sintering in the constant parameters described in section 4.1.

Table 2.
Examples of the results of samples hardness measurements obtained in the course of research for various aging times of pre-expanded granulate

	The hardness	
Aging times, [min]	**D933B**	**D833B**
0	66	79
30	72	82
60	73	80
90	76	71
120	77	68
150	80	62
180	81	60
210	81	
240	83	
270	84	
300	79	
330	70	
360	68	
390	65	
420	64	
450	65	
480	63	
510	62	

Effect of aging time of the pre-expanded granules for the hardness of the pattern (for selected materials) is shown in Figure 8. The presented data shows that the hardness of the pattern depends on aging time of pre-expanded granules. It can be seen that the aging time of pre-expanded polystyrene D933B should be between 150 to 300 min. At the time of approx. 270 min the maximum hardness is obtained. The aging time for the expandable polystyrene D833B should be between 0 to 60 min. At the aging time: 30 min is the maximum hardness of patterns obtained. After exceeding the recommended aging times the hardness begins to decrease. This is related to the diffusion of blowing agent from the interior pellets and worsens sintering of the pellets.

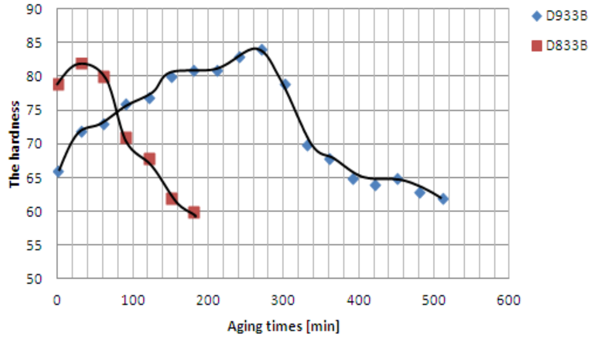

Fig. 8. Effect of the aging time pre-expanded raw materials on the patterns hardness

From the obtained results it can be seen that the aging time of expandable polystyrene at the highest hardness values are coincided with the aging times reached for the highest values of bending strength. It is closely related to better sintering of the granules in the final shaping process.

6. Summary

Concluding, from the research it can be seen that for expandable polystyrene with a specific density (16-27 kg/m3 for foundry) the optimal aging time, at which the expanded polystyrene exhibits the greatest ability to re-expansion, can be found. For the raw material D933B optimal aging time (bending strength ≥ 300 kPa) ranges between 200 ÷ 330 minutes, while for the raw material D833B: 0 ÷ 60 minutes. The patterns hardness for shown aging is also the highest.

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