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Influence of time and pressure of forming a pattern on mechanical properties

T. Pacyniak*, K. Buczkowska, R. Kaczorowski
Department of Materials Technology and Production Systems, Technical University of Lodz,
Stefanowskiego 1/15, 90-924 Lodz, Poland
*Corresponding author. E-mail address: tadeusz.pacyniak@p.lodz.pl

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Abstract

In this paper, the technology of forming patterns on a research station equipped with an autoclave A-600 of Polish company GROM is presented. This study was conducted to determine the influence of pressure and time of forming a pattern on the bending strength. Analysis of the results confirmed that bending strength increases with increasing the pressure. The time of forming a pattern has a similar effect.

Keywords: Innovative foundry technologies and materials, Foundry engineering, Lost foam, Polystyrene patterns, Castings

1. Introduction

The casts production process with use of disposable patterns made from expanded macromolecular materials is known around the world since 1958, originally Shroyer's patent [1]. Initially, it was used in unit and small production. Manual assembling and gluing constituents form polystyrene blocks did not meet the accuracy and dimensions standards, as well as roughness of castings. In the late eighties of the twentieth century, production of the Lost Foam process castings has developed significantly, which made possible to use this process in high dimensional accuracy and repeatability castings manufacturing from both, ferrous and non ferrous alloys. High interest of this technology is caused by considerably lower production and investment costs compared to the traditional technology [2]. This method in comparison to traditional casting in sand molds has several advantages:

- ability to receive the inner surfaces of the casting without cores,
- usage sand without binder (pure sand) eliminates the costly process of molding sands preparing,
- reduces the number of fettling operations due to lack of cores and the parting surface (no trapping),
- reduces the amount of tooling and equipment (foundry moulding machine, mixers to prepare the masses, etc.)
- reduces the workload of the final operation following the absence of flashes, burns, etc. [3]

2. Patterns production in lost foam castings process, tests state

One of the most important stage in casting production technology with Lost Foam method is a process of producing plastic foam models of high-molecular materials. High quality and low density of patterns are necessary to obtain high accuracy and surface smoothness castings. Patterns that meet these requirements shall be obtained in metal matrix. The technological process of producing polymer foam patterns can be divided into two stages. First, the so-called pre-expansion process, where granules are foamed polymer such as polystyrene is subjected to an initial heat treatment, drying and activation. In the second stage of pattern development, the matrix is filled with pre-foamed

pellets, subjecting them to heat treatment. After cooling process, finished pattern is removed from the matrix.[4]
The most commonly used materials are expandable polystyrene (EPS), polymethylmethacrylate (PMMA), polyethylene (PE), polypropylene (PP) and polycarbonate (PC).
Materials used in the manufacture of full mold castings, should provide:

- a proper density of pattern,
- good surface quality of pattern,
- dimensional stability of pattern,
- a proper speed of gasification,
- environmentally friendly,
- the gasification should not leave the solids,
- low price [8]

2.1. Pre-expanding process

Initial foaming of expandable polystyrene beads can be carried out by heating it in boiling water, steam, high frequency currents or infrared radiation [5]. Most pre-foaming is carried out using only steam heaters or in combination with vacuum [3]. In order to obtain foamed granules of minimum possible bulk density, please note that with decreasing density, decreases the strength and hardness of polystyrene which deteriorates the surface quality. Expandable polystyrene is saturated with a blowing agent (isopentane) which evaporating temperature is *28÷30°C*. In the polystyrene expanding process, when blowing agent evaporation temperature is reached the pressure inside the pellets is increased, so starting from the temperature of softening polystyrene
(~ *80°C*), followed by stretching the walls of the begin to streght which increase their volume. At the appropriate expanding temperature of polystyrene (*100÷105°C*), the beads volume increases up to several dozen times. After completion of foaming pellets they are dried and cooled, and then subjected to a process of aging. During aging the beads, air diffuse inside the granules by thin walls. This process occurs because the pressure inside pellets is less than atmospheric pressure due to condensation of blowing agent. With passage of time the blowing agent diffuse outside of granules so in a result their mass decreaces. These phenomena have important influence on activity of granule during forming of pattern in matrix. [3]

The batch pre-expander SC-500 with dryer made by polish company GROM, which is shown on the figure 2, was used to the pre-expanding process. On the figure 1 the scheme of pre-expansion station is shown.

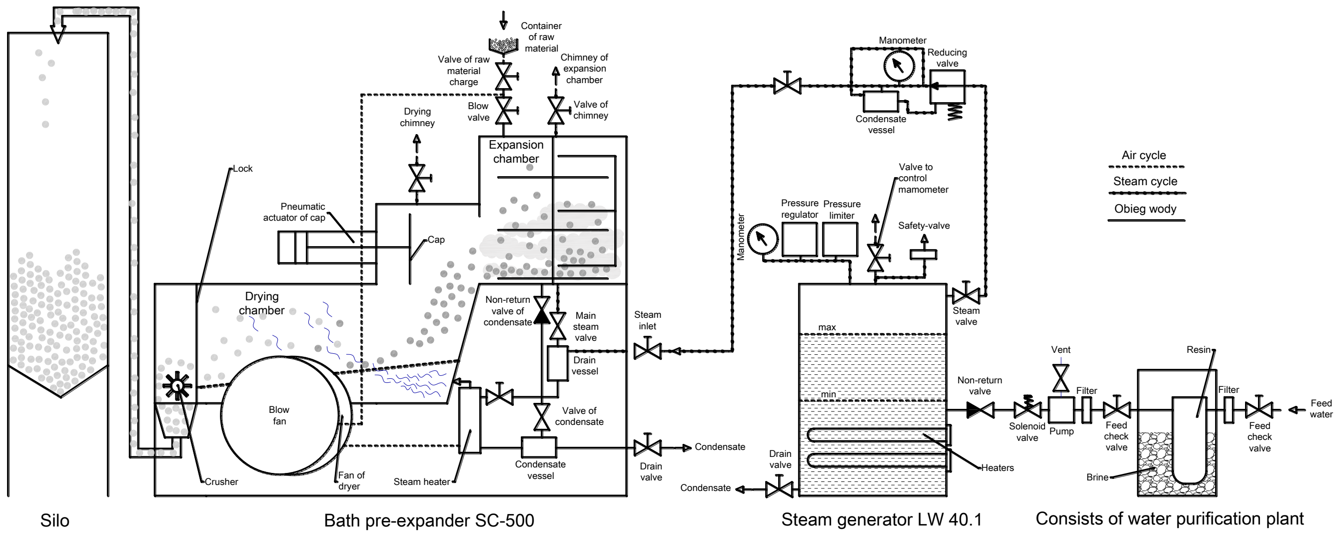

Fig. 1. Scheme station of pre-expansion the polystyrene, equipped with a batch pre-expander [3]

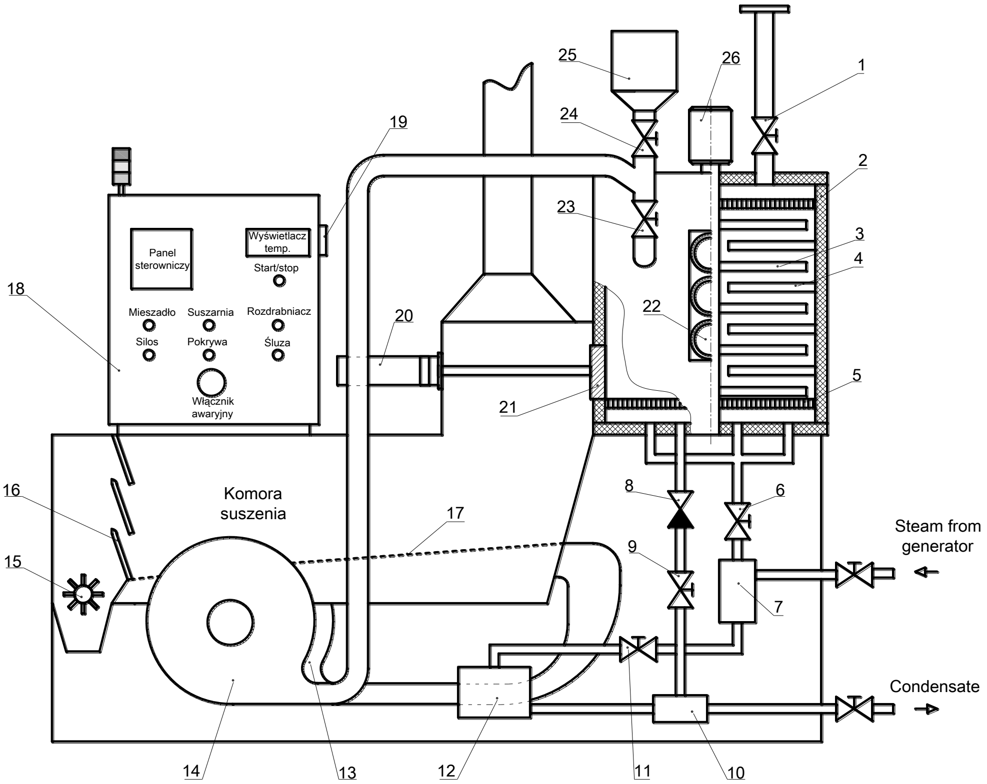

Fig. 2. Scheme a batch pre-expander SC-500 [3]
1 – cut-off valve of the chimney, 2 – chamber of pre-expansion process with thermal insulation, 3 – mixer, 4 –hogging rods, 5 – perforated bottom, 6 – main valve of the steam , 7 –vessel on the drip, 8 – non-return valve of condensate, 9 – valve of condensate, 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

2.2. The process of the shaping of the pattern

Depending on purpose and requirements of castings, patterns may be produced in metal matrix or individually cut out from polisthyrene blocks [4].
The most popular method of patterns formation from frothed high-molecular materials is using matrix especially designed to this process, which are usually made from pure aluminum or aluminium alloys [4, 6]. In this method the pre-expanded pellets are put in a recess in the matrix and then warmed with steam. In the process of re-heating pellets, the blowing agent evaporates inside the granules again, which increases the volume and pressure of the pellets. The pellets pressure on matrix walls grows up (*0,2÷025 MPa*) which results in joining them and in higher temperature (*100 ÷ 110 ° C*) also sintering [7]. Then the matrix and shaped pattern inside the matrix are cooled. During the cooling process of the pattern, vitrification of material (polystyrene) and the condensation of blowing agent takes place. After cooling the matrix is opened and the pattern is removed from the matrix. When the pattern is kept on the air it diffuse into the pellets, while the blowing agent diffuse outside of them. As a result of filling the beads with air, they get slightly elasticity, which causes a slight increase of the patter strength. The density of the pattern must be under control because it affects on such properties as mechanical strength, surface smoothness, amount of gas produced, shrinkage and pattern dimensions [8, 9].

2.2.1. Description of final forming position

To the patterns shaping process, an autoclave A-600 of polish company GROM was used, which is illustrated on the figure 3..

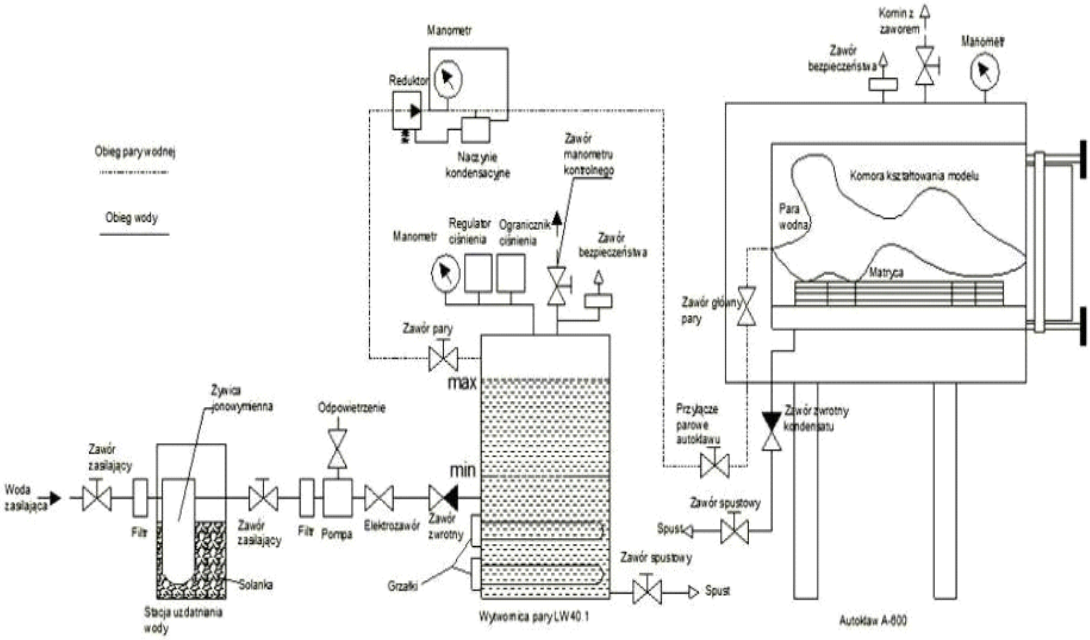

Fig. 3. Scheme of description of final forming position [7]

The autoclave can work in automatic or manual mode. However, before it starts, regardless of the mode, the autoclave chamber must be heated to aprox. 80 ° C. Heating process is performed to ensure the stability of the parameters of the polystyrene model process. After warm-up the actual process of making the model can begin by placing the matrix inside the sealed pre-filled with expended polystyrene model that reproduces the shape. After closing the chamber begins the cyclic process of heating the matrix with specified time of fresh steam provide and removing them from the chamber of autoclave. After realization of desired cycles number the matrix is removed from the autoclave, cooled, and then finished model is removed. Autoclave is ready to continue working immediately after to process finished.

Matrix for the production of EPS patterns was made of aluminum. It consists of four parts, which after folding create three division surfaces. It makes possible to easier taking out the model from the matrix. Figure 4a shows the complexity, and figure 4b presents spread up matrix used to manufacture of tested models.

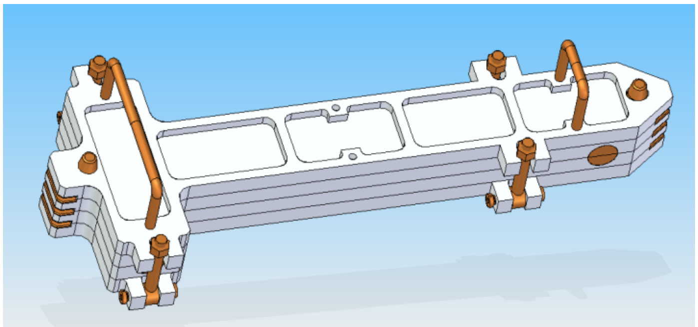

Fig. 4a. The folded matrix predicted to the production of polystyrene patterns [7]

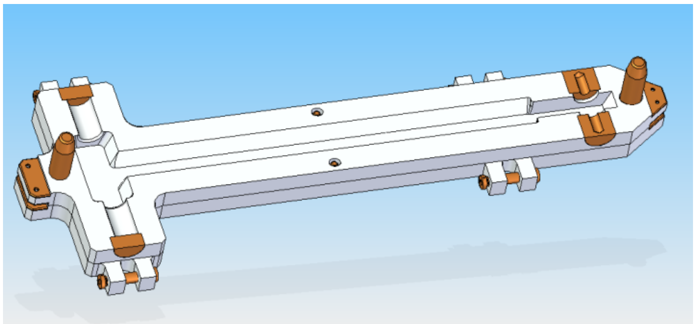

Fig. 4b. The matrix used to the production of polystyrene patterns after the arrangement [7]

Samples with dimensions of 150x28x21 were investigated by bending trength .

2.3 Bending strength tests state

The test stand which is showing in figure 5 fitted with TS-1 is used to determine the strength properties of expansions high-molecular materials allow to bending, crushing and tensile strengths. In this paper the bending strength on polystyrene samples were made according to PN-EN 12089:2000 norm.

The plant has the certificate of calibration of measuring heads. For bending strength investigation there are possible two ranges of the domain of study:

- from 10 N to 100 N,
- from 100 N to 1 kN,

force measurement with an accuracy of 1% of the current indication [10]

Fig. 5. State of the bending strength investigation [10]

3. Preliminary tests of the models formation process

3.1. Materials and the range of tests

The study involved an analysis the model made of from pre-expanded polystyrene during 60 s at pressures 1.15 ÷ 1.4 bar and 30 minutes aging of the banding strength. Then, after calculating the bulk density the pallets was poured into the matrix and subjected the process of the formation position during 120 ÷ 400 s, pressures of 1.25 ÷ 1.40 bar.

For investigations the expanded polystyrene STYROPOR 495 from BASF company containing up to 3,8% pentane, 0,9% isopentane and 1% hexabromocyklodecan. Bulk density expandable polystyrene was 600 kg/m3, and the diameter of the pallets was between 0.3 ÷ 0.7 mm.

3.2. Methodology of tests

After the formation process of the models were cut down to the samples with dimensions 150x28x21, which were then tested of the bending strength. Diagram of the study was carried out as shown in figure 6.

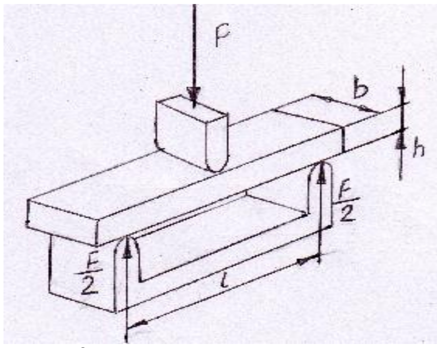

Fig. 6. Schema of sample subjected to the testing on the bending strength

Crushing strength was enumerated from the formula:

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

where,

Rg – bending strength [Pa]

Mg_{max} – bending moment [N·m]

W_x -section modulus [m^3]

F – breaking load [N]

b - width of the sample to the testing [mm]

h – height of the sample to the testing [mm]

L – length of the sample to the testing [mm]

l- the distance among rolls supporting [mm]

3.3. Results and preliminary analysis

Table 1 presents the results of measurements obtained during the on-device TS-1 for various times and pressures of making patterns.

Table 1.
Summary tests results for various times and pressures of the formation models process

Time of sintering [s]	Pressure of sintering [bar]	Bulk density [kg/m^3]	Bend [mm]	Force max [N]	Bending strength [kPa]
120	1,40	21,90	1,54	6,9	76,13
200	1,40	21,55	3,69	19,7	213,07
300	1,40	21,94	6,80	22,6	247,26
400	1,40	22,19	7,17	22,7	257,93
300	1,25	20,73	3,00	11,2	126,64
300	1,30	21,63	3,66	12,5	154,74
300	1,35	21,40	3,75	15,4	181,51
300	1,40	21,20	5,16	17,3	191,30

Figure 7 shows the dependence the force on the bend of sintering in the time 300 s at pressures 1.25 ÷ 1.4 bar

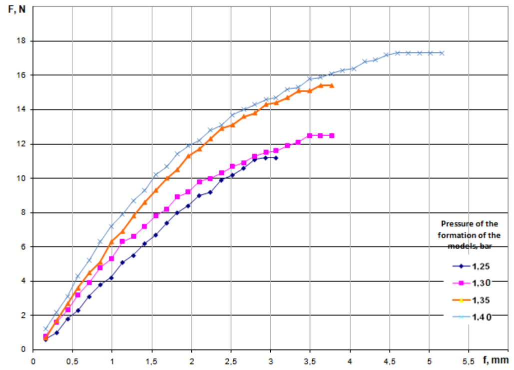

Fig. 7. The graph of the dependence of bend from force

Figure 8 shows the effect of sintering time of models on the bending strength at a constant pressure P = 1.40 bar, which is equivalent to a temperature of 109^{0}C.
From presented data results that the bending strenght depends on the sintering time and with the lengthen of the sintering time the crushing strength grow up.

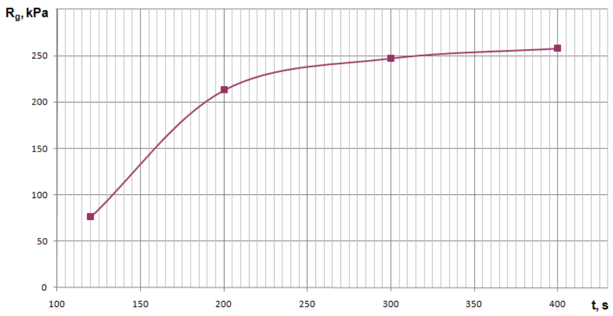

Fig. 8. The graph of the dependence the time of sintering on bending strength with constant steam pressure, P=1,40 bar

Figure 9 shows the effect of sintering pressure on models of the banding strength at a constant time t = 300 s.

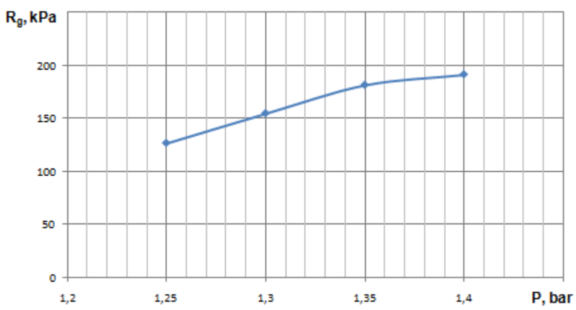

Fig. 9. The graph of the dependence of the sintering pressure on banding strength

The show data follows that the banding strenght depends on the sintering pressure and with the increase of the sintering pressure the banding strength increases.
The banding strength results which were obtained in the paper are not satisfying. It could be depended on low density of polystyrene in the matrix.

4. Conclusions

From the data which were show in this paper, occurs the following:

- banding strength grew with the growth of pressure,
- increasing the time of sintering the banding strength increases,
- the largest increase of bending strength can be observed in the first stage of sintering at constant pressure,
- due to the increase of pressure the bending strength is growing almost linearly.

The banding strength results which were obtained in the paper are not satisfying. It could be depended on low density of polystyrene in the matrix.

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