

# The Influence of the Basic Styrofoam Patterns Final Shaping Parameters on the Resistance Properties

T. Pacyniak\*, K. Buczkowska

Department of Materials Engineering and Production Systems, Technical University of Łódź,  
1/15 Stefanowskiego Street, 90-924 Łódź, Poland

\*Corresponding author: E-mail address: tadeusz.pacyniak@p.lodz.pl

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## Abstract

This work presents the analysis of the final shaping process of the patterns aimed at determining the influence of the pressure and the time of sintering on the resistance to bending. The analysis of the research results proved that when the pressure of the sintering rises and reaches  $P_s=2.1$  bar the resistance to bending increases, above this level of the pressure the resistance value starts decreasing. The time of styrofoam sintering at which the highest bending resistance values were obtained is  $t_s=90$  s. When the sintering pressure is less than 2 bar prolongation of the time of sintering over 90 s causes a slight increase in the resistance, however, at higher pressures prolongation of the time of sintering causes submelting of the styrofoam pattern.

**Keywords:** Foundry, Lost foam, Polystyrene patterns, Casts

## 1. Introduction

The technology of the lost-foam patterns has been known since the 50s of the 20<sup>th</sup> century due to Shroyer's patent [1], however, it was not earlier than in the 80s of the 20<sup>th</sup> century when the casting technology using the foam patterns started to develop fast. At first, the patterns cut from polystyrene blocks and glued were substituted with the patterns made in aluminum forms which precisely reflected the shape of the cast.

Thanks to this, it was possible to start mass production of casts of high precision and repeatability instead of unit and small series production [2].

The use of the Lost Foam technology in relation to the conventional casting technologies apart from lower production and investment costs has many other benefits:

- possibility to obtain holes in the casts without the necessity of using the cores,
- lack of the divided surface and inclination, it naturally increases the dimension precision of the cast and decreases the number of operations required for cleaning of the casts,
- use of clean sand instead of molding sand eliminates the influence of humidity on the defects of the casts, moreover, its regeneration is cheaper,
- decrease in the number of technological devices and equipment (no forms, no mixers to prepare the masses)
- decrease in the labour inputs of the final operations as a result of the absence of joint fins, sintering and so on [3].

## 2. Technological basics of polystyrene pattern making

The following materials are most often used to produce patterns regarding their price and dimension stability: expanded polystyrene EPS known as polystyrene, polymethyl methacrylate (PMMA), polyethylene (PE), polypropylene (PP) and polycarbonate (PC).

In order to obtain the casts of high dimension precision and small surface irregularity the plastics used to make the patterns should guarantee:

- relevant density of the pattern,
- good quality of the pattern surface,
- dimension stability of the pattern
- high mechanic resistance
- relevant fast gasification,
- low price [3]

The process of pattern making from the foamed polymers can be divided into two stages. The first stage is the process of pre-foaming in which the granules of foamed polystyrene are subjected to initial thermal treatment, drying and activation.

The second stage is the stage of final shaping based on filling the metal matrixes with pre-foamed granules, usually by ejecting them from a pneumatic pistol, and then heating the polystyrene granules which are in the matrix reflected the shape of the ready pattern again. The ready pattern is taken out of the matrix after its preliminary cooling.

Aiming at the lowest possible bulk density of the foamed granules it should be remembered that when the density decreases the strength and hardness of the polystyrene also decrease, thus the surface quality deteriorates.

### 2.1. Pre-foaming

Pre-foaming is carried out in order to obtain the required density of the foamed polymer. There are several ways of pre-foaming of polystyrene granules:

- heating in boiling water,
- steam heating,
- high frequency current heating
- infrared heating [4].

Pre-foaming is often performed using steam heating [3].

Foaming polystyrene is saturated with a sponging agent (isopentane) whose steaming temperature should be  $28\div 30^{\circ}\text{C}$ . In the process of the polystyrene expansion in the temperature of the sponging agent steaming the increase in the pressure inside the granule occurs creating the polystyrene melting temperature, which is at about  $80^{\circ}\text{C}$ , the sides of the granules stretch leading to expansion of its volume. At the temperature proper to pre-foaming of polystyrene ( $100\div 105^{\circ}\text{C}$ ), a dramatic, even by multiples, increase in the granules volume occurs. When foaming ends, the granules are dried and cooled and then are subjected to

conditioning – activation. During conditioning, diffusion of the atmosphere air inside the granules through their thin walls takes place. This process happens because inside the granules the pressure is lower than the atmospheric pressure as a result of the sponging agent condensation. When time passes, the steaming sponging agent diffuses outside of the granule and as a result its mass decreases. These phenomena have an important influence of the activity of the granules during the process of pattern shaping in the matrix. [3, 4, 5].

### 2.2. Final shaping

Making the patterns in a specially designed matrixes usually made of aluminum or its alloys is currently the most popular method of shaping patterns from foamed plastics. Regarding the specificity of the process, the choice of the material used for the production of the matrixes is determined by the high coefficient of thermal conductivity, for aluminum this coefficient is  $\lambda \approx 175\text{W/m}^2\text{K}$  [3,6,7].

After placing the pre-foamed granules in the matrix cavity they are heated with water steam. In the process of repeated heating evaporation of the sponging agent inside the granules takes place causing their volume and pressure to increase. The pressure of the granules on the walls of the matrix increases significantly which causes their joining, and at a higher temperature ( $100\div 110^{\circ}\text{C}$ ) their sintering [3, 8]. The process of sintering can be performed by heating the granules from the walls or additionally passing the steam directly through the pattern. After the process of sintering the matrix and the pattern which is in it are cooled, and as a result vitrification of the plastic (polystyrene) and condensation of the sponging agent occur. After cooling the pattern is taken out of the matrix and then conditioned in order to obtain dimensional stability and higher resistance to bending.

During the final shaping process the most important parameters are time and temperature. In practice it is easier to control the steam pressure than the temperature [13].

The density of the patters mainly depends on the bulk density of the pre-foamed polystyrene, and the density of the model itself is about 20% higher than the bulk density of the pre-foamed polystyrene. It is connected with better density of the granules in the patters [13].

## 3. Polystyrene patterns shaping stand

### 3.1. The description of the stand

The process of styrofoam patterns shaping was carried out on the test bench presented in Figure 1.

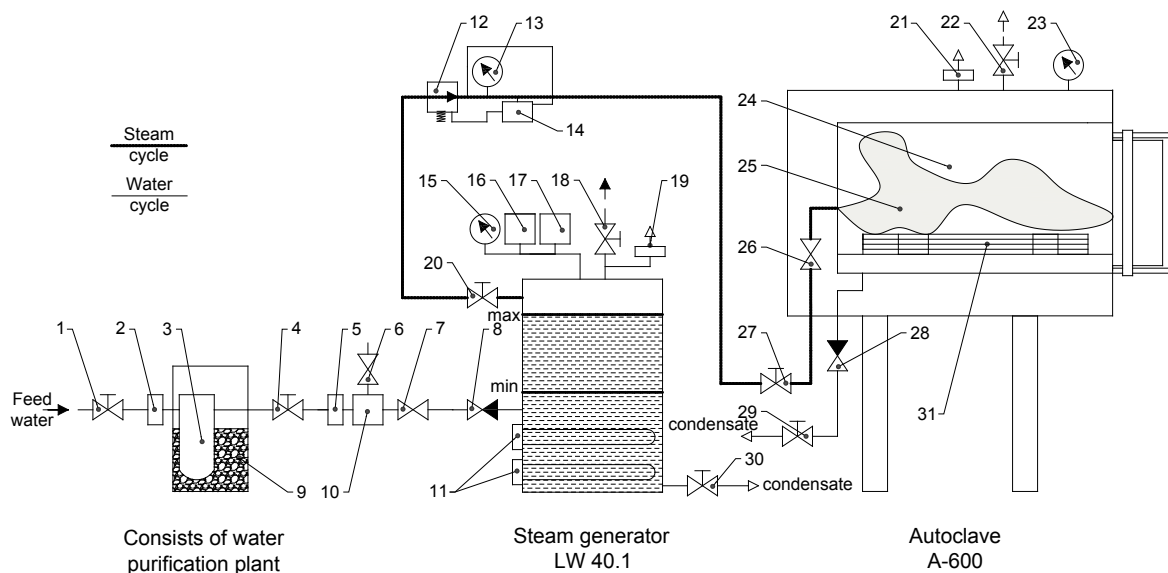


Fig. 1. Scheme of description of final forming stand [6].

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 inlet, 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

The stand was equipped with an A-600 autoclave manufactured by GROM, a steam generator and a water purification plant. Before starting work, the autoclave chamber should be heated to the temperature of about 80°C. The heating process is carried out in order to guarantee stability of the styrofoam pattern shaping parameters. After heating it is possible to start the actual process of pattern shaping putting the closed matrix filled with the pre-foamed polystyrene inside. After closing the chamber the matrix is heated at a given time and the sintering pressure. When the process finishes, the matrix is taken out of the autoclave, cooled and then the ready pattern is taken out [6].

### 3.2. The description of the test matrix

The matrix made of aluminum alloys was used in the process of final shaping of the pattern. The choice of aluminum alloys is determined by the specificity of the sintering process. The matrix filled with granulate is first heated and then cooled, so the material from which the matrix is built should have a high coefficient of thermal conductivity  $\lambda$ . For aluminum alloys the coefficient is  $\lambda \approx 175 \text{ W/m}^2\text{K}$ , however, for steel it is only  $\lambda \approx 60 \text{ W/m}^2\text{K}$ . The matrix has special deaerating screws to deaerate the net of the matrix during its filling with polystyrene granules and make the intake of water steam which heats the matrix easier.

The matrix with the dimensions 30x30x300 used for making samples of the bending strength tests is presented in Figure 2 [14].

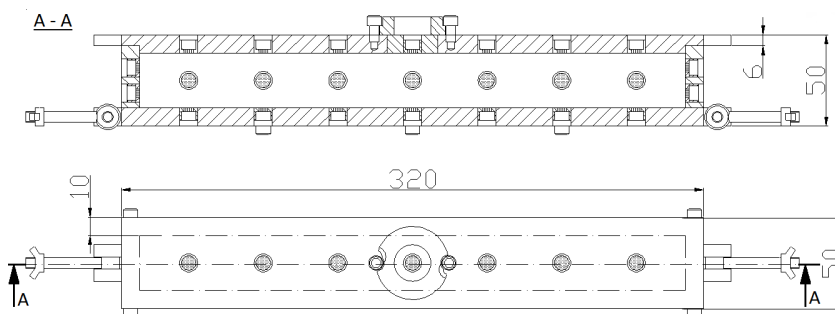


Fig. 2. The scheme of the matrix used for making specimens for bending strength tests [14]

### 3.3. The description of the stand for filling the matrix

The scheme of the stand used for filling the matrixes with pre-foamed polystyrene granulate is shown in Figure 3.

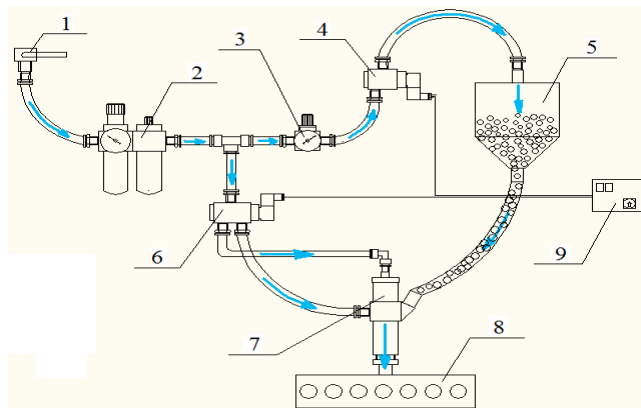


Fig. 3. The stand used for filling the matrixes with pre-foamed granulate [14]

1- compressed air valve, 2- air preparation block, 3- reducing valve, 4- electric distributive valve 3/2 (3-way, 2-position) electric distributive valve, 5- pressure vessel for granulate, 6- electric distributive valve 5/2 (5-way, 2-position), 7- pistol for granulate, 8- matrix, 9- operation panel

Compressed air from the device is delivered to the system through the ball valve (1). The opening of the valve causes circulation of the air through the polyurethane cable to the air preparation block (2), which consists of two elements: the filtration-reduction assembly and the air lubricator. The air preparation block allows regulating and setting the relevant pressure and holding it at a stable level. Purified and reduced air is directed to the electric distributive valve (6) responsible for operation of the pistol (7). The electric valves (6) and (4) are controlled electromagnetically, the return to the initial position happens with the help of the pressure and spring.

Compressed air of the relevant pressure allows a higher density of the granules inside the matrix (8). As soon as the matrix is filled with pre-foamed granulate the pistol closes and the compressed air supply to the vessel stops. [14].

## 4. The authors' own research

### 4.1. The scope, aim and the materials for the research

D933B foaming polystyrene produced by Ineos Nova was used for the research. The bulk density of the polystyrene before pre-heating was  $620 \text{ kg/m}^3$ , the diameter of the granules was within the range of  $0.2 \div 0.4 \text{ mm}$ . The research was aimed at determining the influence of the time and sintering pressure parameters on the bending resistance of the pattern made of pre-

foamed styrofoam in the time  $t_s=90 \text{ s}$  and pressure  $P_s=1.4 \text{ bar}$  and conditioned for 90 min. The bulk density of foamed polystyrene was  $22.7 \text{ kg/m}^3$ .

Final shaping was carried out in the A-600 type autoclave manufactured by GROM for the times  $t_s=45 \div 120 \text{ s}$  and sintering pressures  $P_s=1.4 \div 2.7 \text{ bar}$ .

The research was aimed at determining the optimal time and sintering temperature of polystyrene.

### 4.2. The stand for testing the bending resistance

The test bench presented in Figure 4 is equipped with the TS-1 device designed to test resistance properties of foamed large-particle plastics. The stand allows determining the bending resistance, compressive strength and tensile strength. The current work presents the bending resistance tests of the styrofoam specimens according to PN-EN 12089:2000.

There are two ranges of the force measurement used in the bending tests:

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

precision of the force was 1% of the current registration [6, 13, 15].



Fig. 4. The stand for bending tests [15]

### 4.3. The research methodology

To make the specimens, a specially made matrix was used. It is shown in Figure 2. From the ready patterns the specimens with the dimensions of  $150 \times 28 \times 22$  were cut out and then subjected to bending tests to determine their strength. The diagram of the stand for strength tests is presented in Figure 4.

The bending resistance was determined using the formula:

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

where:

$R_g$  – bending resistance, [Pa]

$M_{gmax}$  – bending moment, [N·m]

$W_x$  – coefficient of the complete rectangular cross-section of bending, [m<sup>3</sup>]

$F$  – breaking load, [N]

$b$  – width of the specimen, [mm]

$h$  – thickness of the specimen, [mm]

$L$  – length of the specimen, [mm]

$l$  – distance between the supporting rolls, [mm].

## 5. Research results analysis

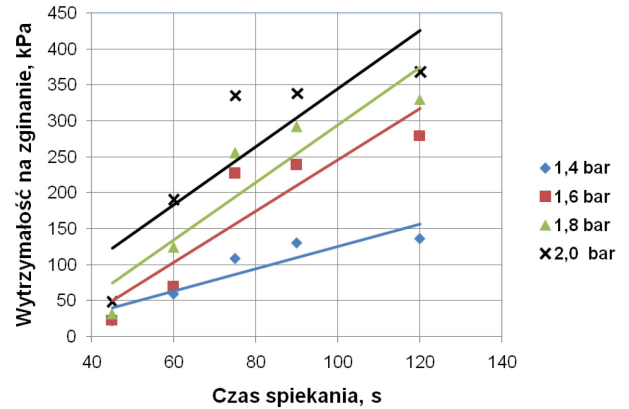
Table 1 presents the results of the measurements obtained during the tests on the TS-1 device for different times and pressures of the pattern shaping process. The results of the measuring which meet the requirements regarding the resistance to bending of the models made using the Lost Foam technology were marked.

Table 1.

Example results of resistance to bending measurements during the test using the TS-1 device for different times and pressures of the pattern shaping process

Sintering pressure	Time of sintering t[s]					
	P[bar]	45	60	75	90	120
		<b>Resistance to bending <math>R_g</math> [kPa]</b>				
1.4		22	59	109	130	137
1.5		6	52	95	259	345
1.6		24	71	227	239	280
1.7		14	70	161	278	309
1.8		32	125	256	293	330
1.9		46	137	267	347	327
2		49	191	336	339	369
2.1		97	176	314	405	403

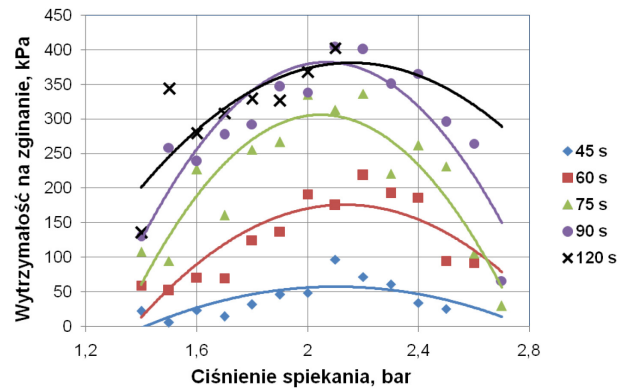
The influence of the time of sintering on the bending resistance is presented in Figure 5. It follows from the presented results that the bending resistance depends on the time of sintering. It can be noticed that if the specimen is heated for more than 90 s the bending resistance increases, and at higher pressures longer sintering causes deformation of the specimen.



[wytrzymałość na zginanie – resistance to bending; czas spiekania – time of sintering]

Fig. 5. The influence of the time of the pattern sintering on the resistance to bending at a constant pressure which is  $P_s = 2.1$  bar

Figure 6 presents the influence of the sintering pressure of the pattern on its resistance to bending. It follows from the presented data that the resistance to bending depends on the sintering pressure, and the maximum resistance to bending was obtained at the sintering pressure equal to 2.1 bar. At higher pressures the specimens start shrinking softly and at longer times they are subjected to complete deformation.



[wytrzymałość na zginanie – resistance to bending; ciśnienie spiekania – sintering pressure]

Fig. 6. The influence of the sintering pressure of the pattern on its resistance to bending at a constant time equal to  $t_s = 90$  s

Figure 7 presents the example photograph of the specimen and its breakage. The specimen surface is vitreous and on the breakage it can be noticed that it broke not only on the border of the grains but also through the grains. It testifies that the grain sintering of the material is very good and its resistance is excellent.

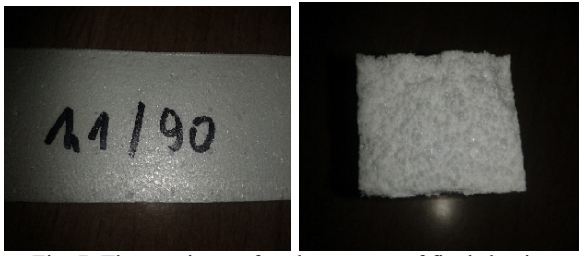


Fig. 7. The specimen after the process of final shaping

## 6. Conclusions

It follows from the presented research results that:

- the maximum resistance to bending was obtained for the time of sintering equal to 90 s,
- longer sintering of the polystyrene at the pressures less than 2 bar slightly influence on the increase of the resistance to bending,
- at the pressures more than 2 bar the longer sintering of the specimen causes the deformation of the material,
- at the pressure 2.1 bar the highest bending resistance was obtained,
- when using the pressures more than 2.1 bar the polystyrene resistance to bending decreases, and if it is more than 2.4 bar the material does not meet the requirements concerning the resistance of the styrofoam patterns to bending.

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