

Test Bench for Analyzing the Lost Foam Process

R. Kaczorowski*, P. Just, T. Pacyniak

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

* Corresponding author. E-mail address: rafal.kaczorowski@p.lodz.pl

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Abstract

The current work presents and describes the test bench for analyzing the lost foam process, especially measuring of the pressure of gases in the gas gap and continuous measuring of the rate of rise of the bath level when pouring the liquid metal into the mould. A series of preliminary research was carried out on the bench which was aimed at determining the influence of the basic parameters of the process, i.e. the density of the styrofoam pattern, thickness of the refractory coating applied on the pattern, kind of the alloy and the temperature of pouring on the mould cavity by the liquid metal and the pressure of gases in the gas gap.

Keywords: Casting, Lost foam, Styrofoam patterns

1. Introduction

The world interest in the lost foam process started in the eighties of the twentieth century when the technological development enabled using the process for mass production of highly precised and dimensionally accurate casts from non-ferrous and ferrous alloys. A lot of interest in this technology of cast-moulding is caused by lower production costs and investments in comparison to the conventional method [1]. This method in comparison to conventional casting in the traditional moulding sand has a number of advantages, such as:

- possibility to obtain internal surface repetition of the casting without using cores,
- much lower production costs,
- the use of the moulding sand without any binding materials eliminates the costly process of moulding sand preparation,
- decreasing the number of casting clearing operations regarding the lack of cores and the division surfaces of the pattern (no joint fin),

- reducing the number of devices and technological equipment (no moulding machines, mixers for preparation of the moulding sand etc.),
- decreasing the labour inputs in the final operations as a result of no joint fins, burning and so on.

The lost foam process starts from making of a single-use pattern from foamed polymer, for example, foamed polystyrene. The foamed polymer pattern is covered with a ceramic refractory coating which constitutes a working surface of the mould and then is formed in sand without banding clay. In order to obtain the relevant compactness of the moulding sand the form is subjected to vibration, and then it is poured with the liquid alloy. While filling the mould cavity, the polymer pattern is subjected to thermal degradation and gradually its volume is replaced by the liquid alloy so, that after hardening it makes a cast of the shape of the pattern. Thermal degradation of the polymer pattern at the front of the liquid metal has a lot of influence on the cast quality. Endothermic degradation of the polymer pattern has an important influence on the process of the mould cavity filling. The problems connected with the mould cavity filling process, degradation and

gasification of the polymer pattern determine the quality of the obtained cast [2].

2. Technological aspects of the cast making process in the lost foam process

In the lost foam process there is a number of factors which do not appear in conventional technologies and which have a sustainable influence on the final result. The most important role is played by:

- **density of the foamed polymer** which has an important influence on the mechanical resistance, surface irregularity, quantity of the gas produced during gasification, shrinkage and dimension stability of the pattern. A relevantly selected density of the pattern guarantees the correct filling of the mould by the liquid alloy for a certain shape and dimensions of the cast and at the same time saving the relevant hardness and irregularity of the pattern. When the density of the pattern decreases, the casting speed increases and the gas pressure in the gas gap and its size decrease. The increase in the casting speed guarantees the right obtainment of the casts of a very complicated shape and small wall thickness. The smaller gas gap and the smaller gas pressure inside of it decrease the probability of destruction of the pattern. The smaller the density of the pattern is the bigger is the speed of casting; that is why in foundry practice smaller densities of a pattern are used. The most common materials used for making foam patterns are: expanded polystyrene (EPS), polymethyl methacrylate (PMMA). The most frequently used material is expanded polystyrene – styrofoam. The recommended densities of the EPS styrofoam are presented in Table 1 [2].

Table 1.
Recommended densities of the styrofoam patterns for typical casting materials [2]

| Kind of alloy | Casting temperature °C | Density of the EPS pattern kg/m ³ |
|------------------|---------------------------|--|
| Aluminium alloys | 705-790 | 24-27 |
| Copper alloys | 1040-1260 | 20-21.6 |
| Grey iron | 1370-1455 | ≤20 |
| Cast-steel | 1595-1650 | ≤17.6 |

- **casting (pouring) temperature** which is determined by the kind of the casting alloy. The process of thermal degradation of the styrofoam depends on the temperature at which degradation takes place. Due to degradation at the temperature of about 500°C volatile products mainly consist from styrene monomer C₈H₈ [4]. When the temperature increases the monomer particles are subjected to additional degradation into light hydrocarbons such as C₇H₈, C₆H₆, C₂H₄ and C₂H₂. At the temperatures over 1000°C thermal degradation of the polymer causes the appearance of a numerous quantity of carbon in the form of graphite and even the appearance of hydrogen, however, it was not possible to identify more than 50% of the compounds in research [4]. Depending on the casting temperature of 750 and 1300°C the volume of the gases appearing from the polystyrene mass was correspondingly: 250 cm³/g and 800 cm³/g [5]. Thermal degradation of the foam pattern also depends on the kind of the plastic. Table 2 shows the

physical parameters for the patterns made from expanded polystyrene (EPS) and expanded polymethyl methacrylate (PMMA).

Table 2.
Physical parameters of the basic polymers user in the lost foam [5]

| | EPS | PMMA |
|--|-----|------|
| Volume of the extracted gas at temp. 750°C (cm ³ /g) | 230 | 273 |
| Volume of the extracted gas at temp. 1300°C (cm ³ /g) | 760 | 804 |
| % of non-volatile residues at temp. 1400°C | 15 | 3 |

- **size and configuration of the gate assembly** whose task is to ensure easy filling of the mould and affecting the metal crystallization process [6]. The time of pouring is usually determined by the minimal cross section of the gate assembly that is the cross section of the in-gate. In the lost foam process, regarding its specificity, when pouring the mould with the alloy, some of the thermal energy of the metal is transformed into gasification of the styrofoam pattern. It leads to a decrease in the temperature of the metal increasing its viscosity and making it difficult to obtain casts of a complicated form. It can be prevented by increasing the temperature of the liquid alloy; however, it can cause deterioration of the cast microstructure. That is why, the aim is to decrease the time of pouring and increase the speed of mould cavity filling with metal. The speed can be controlled by the size of the in-gate cross section.

- **value of the vacuum pressure in the mould** which influences the system of the pressures effecting the bath of the metal filling the mould cavity. The pressure in the gas gap connected with the gasification of the pattern reacts against the hydrostatic pressure coming from the metal column in the gate assembly. The pressure in the gas gap depends on the quantity of gases appearing as a result of thermal degradation of polystyrene, and on the number of gases filtrated from the mould cavity through the refractory coating connected with its permeability and thickness. The use of vacuum pressure in the mould enables improvement of the gas filtration through the coating (the bigger pressure difference) and increasing the pouring speed.

- **the refractory coating** applied on the pattern. It somehow makes up the working surface of the mould and prevents metal penetration into the sand. The condition of the cast surface depends on the coating. The coating used in the lost foam process should be characterized by:

- **good permeability** [2] which allows gas and liquid products of polystyrene degradation escape from the mould cavity. The lower permeability of the refractory coating is the bigger is the gas pressure in the gas gap. It follows from this that the lower the permeability of the refractory coating is the more difficult is the gas filtration from the gas gap, thus the gas pressure is higher. Too little permeability can cause gasification of the cast, cracking of the coating and the metal outflow. In such a case defects appear on the cast [7]
- **relative thickness**. The more the thickness of the coating is the higher is the pressure in the gas gap. The thick coating makes the gas filtration much more difficult as the increase

in the thickness prolongs the way which it should go through.

The use of coatings with permeability under $K_p=5 \cdot 10^{-9} m^2/(Pa \cdot s)$ and the thickness of the coating over $s=0,5mm$ has a significant influence on the gas pressure increase in the gas gap which is not beneficial as it prolongs the time of casting of the mould and can cause cracking on the surface of the cast. As a result the cast of lower surface quality is obtained, and in some cases it is possible that the mould would not be filled to the full [3].

It should be noted that all the above mentioned parameters of the lost foam process have a direct connection with the gas pressure value in the gas gap and influence on the speed of the mould cavity casting. Having taken this into consideration it was decided to build a test bench which would allow analyzing the influence of the density of the foam pattern, permeability and the thickness of the coating, kind of alloy and the pouring temperature on the pressure in the gas gap and the speed of metal bath level rising.

3. Description of the test bench

The test bench for the lost foam process analysis is equipped with a continuous measuring system with a MLA-SK linear module, SSK-1 controller and MP16B converter which enables continuous registration of the casting speed. The scheme of the test bench for continuous measuring of the casting speed is presented in Figure 1.

The bench is equipped with the moulding flask (7) with double walls and a perforated bottom (9) fastened to the ground with the help of vibration isolators (16), vacuum device and power operated electric vibrator (14) used for compacting the moulding sand (dry sand without binding material) controlled by the inverter (5) which enables selection of the optimal frequency and amplitude of vibration. It allows obtaining the proper compaction of the quartz sand. The moulding flask construction allows connecting the compressed air device and vacuum device (13), air filter (12) and heat discharge tank (11) and vacuum gauge (10). Special valves lead the compressed air to the air chamber (15) under the perforated bottom (9) in order to fluidize the sand bed in the moulding flask.

The connection of the flask space to the vacuum was used to analyze the influence of the pressure in the mould on the process of pouring and to extract gases from the mould. Moreover, the use of vacuum pressure in the mould stabilizes during the process of compaction of the sand in the flask when filling the mould cavity with liquid casting alloy.

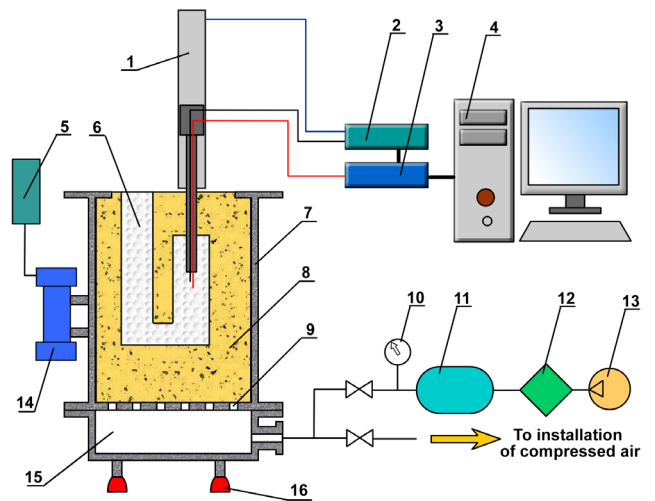


Fig. 1. The diagram of the test bench for forming, pouring and analyzing of the lost foam process

- 1 – linear module MLA-SK with K type thermoelement and electrode, 2 – controller SSK-1, 3 – MP16B type converter, 4 – personal computer, 5 – inverter, 6 – styrofoam pattern, 7 – moulding flask, 8 – quartz sand without any binding materials, 9 – perforated bottom, 10 – vacuum gauge, 11 – heat discharge tank, 12 – air filter, 13 – vacuum pump, 14 – electric vibrator, 15 – air chamber, 16 – flexible elements (vibration isolators)

The bench is equipped with a system of continuous registration of the metal bath position in the mould cavity. It consists of a linear module MLA-SK (1), a controller SSK-1 (2), converter of type MP16B (3) and a personal computer PC (4) used for data acquisition. The controller of the type MP16B is a device used for measuring the tensors coming from the thermoelectric temperature sensors which guarantee galvanic separation between the power supply and certain measuring rails. It guarantees simultaneity of measuring in all the channels, measuring of the relating temperature with the help of a type PT100 thermo resistant temperature sensor and has an input counting the impulses in the TTL standard. It has 12 low tension inputs for cooperation with the thermoelectric sensors, 3 inputs for measuring of the standard tension signals within the tension range between 0 and 5V and 1 input for cooperation with the PT100 thermoresistant sensor and is equipped with a stable source of 500 μA electric current with an automatic compensation of the wire resistance to the value of 20 ohm. The SSK-1 controller is designed for cooperation with the MLA-SK linear module. Together with the module it makes a complete device for measuring the movement and the temperature of the front of flame of the flowing metal. The design of the controller enables realization of two basic operating modes by the linear module – the mode of probe placement and the measuring mode. The module is powered by a standard stepper motor and the rotation mode of the wheel gear is changed into linear movement of the measuring probe with the help of a rack. The PDOC – 16USB software is used to register and analyze the data which allows

measuring and graphic presentation of the results in real time. The view of the panel is presented in Figure 2.

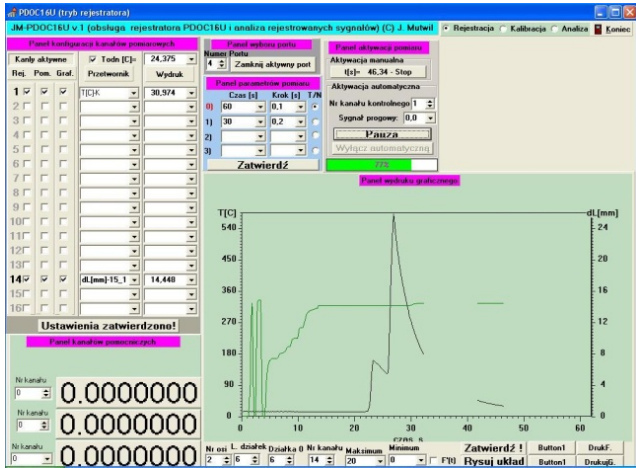


Fig. 2. The view of the registration panel

A complete test bench of forming and casting for continuous measuring and registering of the position and speed of casting, temperature of alloy and pressures in the gas gap is shown in Figure 3.



Fig. 3. The testing bench for forming and casting (real view)
 1 – vacuum gauge, 2 – inverter, 3 – stator, 4 - SSK-1 controller , 5 - MP16B type convertor, 6 – mould flask with perforated bottom, 7 – vacuum device valve, 8 – compressed air device valve, 9 – MLA-SK linear module, 10 – mechanical electric vibrator

The test bench of forming and pouring is also equipped with the system of measuring the pressure in the gas gap with its diagram presented in Figure 4. Its basic element is the A-10 piezoresistive pressure sensor manufactured by Wika. This sensor requires a separate 24V power supply, thus the use an adapter is required. The sensor was attached to the steel tube connecting it to the module in which a measuring hole was made. Registration was made using the MP16B convertor.

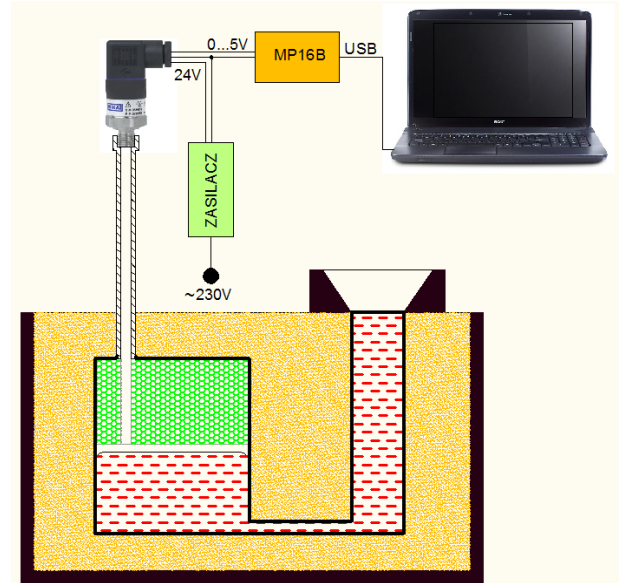


Fig. 4. The diagram of the system for measuring the pressure in the gap

4. Preliminary research results

Figure 5 presents the real course of the pouring speed change depending on the pattern density when poured with silumin. The courses were registered for the pattern at which a 0.5 mm coating of the same type was applied and the cross section of the in-gate was $F_{wd}=1 \text{ cm}^2$. It follows from the figures that the pouring speeds are higher when the pattern density is lower. The nature of the change in the pouring speed for both patterns density is similar. The rate of the bath level rising of the alloy increased gradually and reached the maximal value at half of the time of filling the mould cavity.

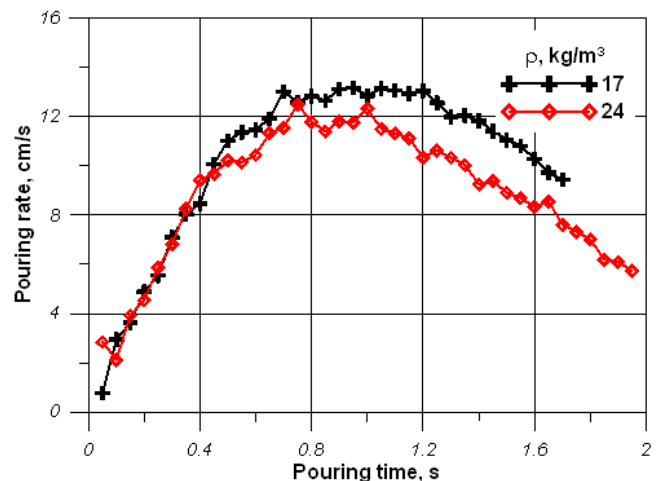


Fig. 5. True pouring rates for different density of the pattern when poured with silumin

The exemplifying influence of the silumin pouring temperature on the pouring rate is presented in Figure 6. The shown research results were carried out for the pattern with the density of $\rho=19 \text{ kg/m}^3$ and in-gate cross section of $F_{wd}=2.25 \text{ cm}^2$. It follows from Figure 6 that for a higher temperature of pouring a slightly higher rate of the bath level rising in the mould cavity was registered. It means that the pouring temperature has a minor influence on the process of the mould casting.

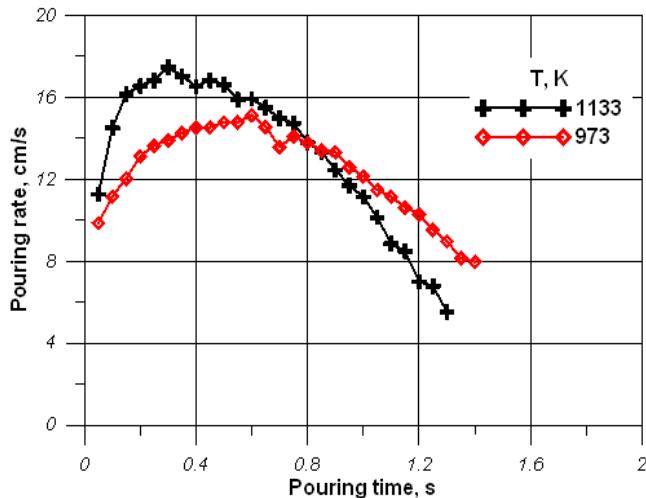


Fig. 6. True pouring rates for different silumin pouring temperatures

The analysis of the influence of the refractory coating thickness applied on the styrofoam pattern was also carried out on the test bench. The exemplifying results for one layer of the coating (thickness $s=0.5 \text{ mm}$) and two layers ($s=0.9 \text{ mm}$) are presented in Figure 7. It follows from the data that much higher pouring rates are obtained at a smaller coating thickness as it makes the filtration of the gases through the coating much easier. For the thickness of the coating $s=0.9 \text{ mm}$ the pouring rate is almost twice lower in comparison to the thickness $s=0.5 \text{ mm}$.

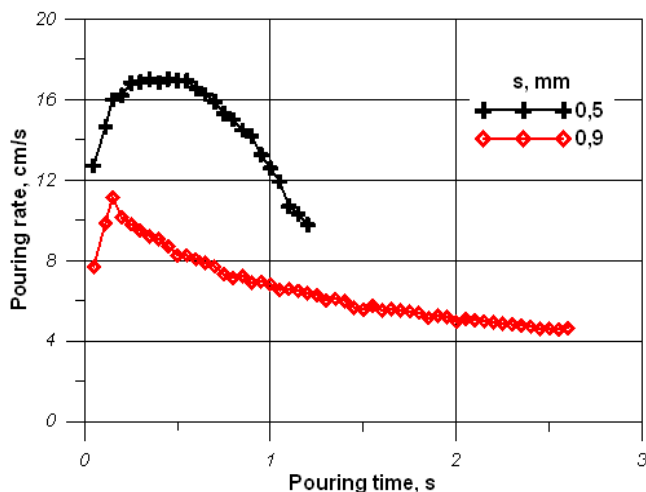


Fig. 7. True pouring rates for different refractory coating thicknesses on the pattern when pouring with silumin

The test bench also enabled the gas pressure measuring in the gas gap. The comparison of the pressure change in the gas gap when pouring the mould with silumin for two densities of the pattern $\rho=19$ and 24 kg/m^3 is presented in Figure 8. It follows from it that when the pattern density increases the pressure in the gas gap also increases. For the tested pattern densities the increase in the pressure of 1 kPa was observed.

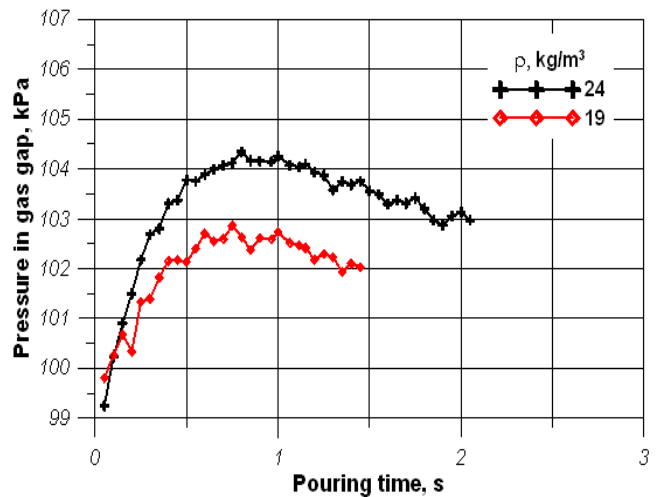


Fig. 8. The measured gas pressure in the gas gap for different pattern densities when it is poured with the silumin

Figures 9 and 10 present the influence of the pouring temperature on the course of change of the gas pressure in the gas gap, correspondingly: when it is poured with silumin and with cast iron. In follows from the analysis of Figure 9 that when the temperature increases the gas pressure in the gas gap decreases. This tendency can be observed for two extreme pouring temperatures $T=973$ and 1133 K .

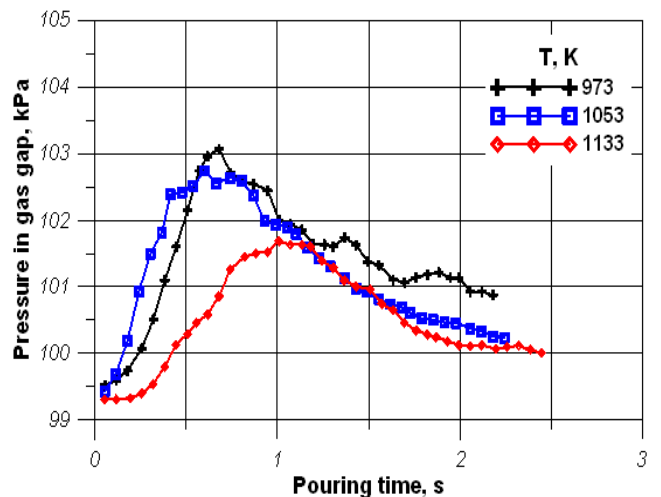


Fig. 9. Gas pressures measured in the gas gap for different temperatures when pouring with silumin

However, in the case of pouring the mould with cast iron, similar to that of silumin, the pressure in the gas gap decreases

when the pouring temperature rises. In comparison to aluminum alloy the pressures are much higher and for the pouring temperature $T=1523$ K the maximum value of the pressure reaches about 119 kPa.

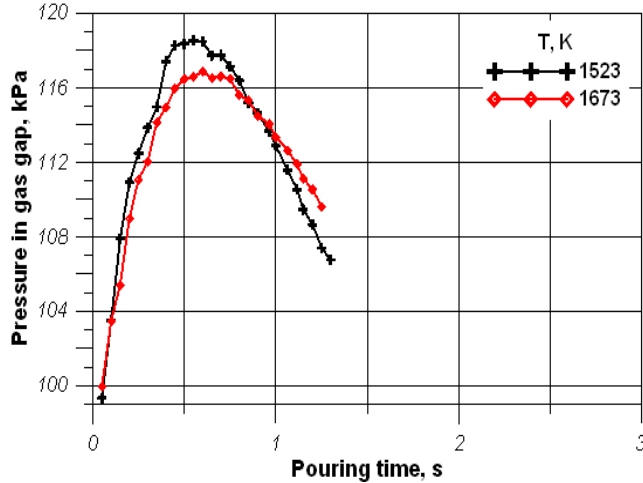


Fig. 10. Gas pressures measured in the gas gap for different temperatures when poured with cast iron

Gas pressures measured during the experiments are slightly different from those presented in works [3, 8]. The difference can be caused by introducing large interferences during the pressure measuring. The use of the tube connecting the pressure sensor with the mould cavity causes the increase in the volume in which the measuring takes place. This volume is a dozen times higher than the gas gap volume, thus the values of the measured pressure are lower.

5. Summary

The test bench for forming and pouring in the lost foam process presented in the present work enables continuous measuring of the front of the liquid alloy during filling the mould cavity, thus it is possible to determine the pouring speed and the gas pressure measuring in the gas gap. Together with the test

bench for preliminary foaming and shaping equipped with the foaming machine and the autoclave [9, 10] it makes up a test bench which allows complete making of casts using the lost foam method and carrying out the research of the lost foam process.

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