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## GAS ATMOSPHERE FORMED IN CASTING BY FULL MOLD PROCESS

### ATMOSFERA GAZOWA WYSTĘPUJĄCA PODCZAS WYKONYWANIA ODLEWÓW W TECHNOLOGII PEŁNEJ FORMY

A test mold was designed to investigate the full mold process. Pressure changes in a gap developing between the pattern made of foamed polystyrene and the raising column of liquid alloy were determined. Studies were conducted pouring molds with cast iron and with AK11 silumin. It was found that pressure is significantly higher in the case of cast iron, due to a higher rate of pattern decomposition and more advanced dissociation of hydrocarbons. The increase in pressure was observed to have no significant effect on changes in the pouring rate as it was compensated by higher metallostatic pressure. The increase of pressure occurs immediately after the start of pouring, it reaches a maximum and then stabilizes or decreases smoothly as a result of the drop in metallostatic pressure. The temperature of pouring has a significant effect on the decomposition rate of hydrocarbons evolving from the metal. During pouring of cast iron, the presence of hydrogen was revealed. It was particularly evident across the gas-permeable coating, where the concentration has exceeded 40%. Hydrogen precipitation was accompanied by an evolution on the casting surface of considerable amounts of pyrolytic carbon. It was found that gases forming in the gap were totally free from oxygen.

*Keywords:* casting, full mold, formation of the gap

Zaprojektowano próbną formę do badania procesu full mold. Określono zmiany ciśnienia w szczelinie powstającej pomiędzy styrodurem modelem a podnoszącym się ciekłym stopem. Badania prowadzono przy zalewaniu form żeliwem oraz siluminem AK11. Stwierdzono, że ciśnienie to jest znacznie wyższe w przypadku żeliwa, co wynika z większej szybkości rozpadu modelu i dalej posuniętej dysocjacji węglowodorów. Wzrost ciśnienia nie powoduje jednak istotnej zmiany szybkości zalewania, ponieważ jest on kompensowany wyższym ciśnieniem metalostatycznym. Wzrost ciśnienia następuje bezpośrednio po rozpoczęciu zalewania, osiąga ono maksimum poczem stabilizuje się lub łagodnie maleje w wyniku zmniejszania ciśnienia metalostatycznego. Temperatura zalewania ma istotny wpływ na stopień rozpadu, wydzielających się z modelu węglowodorów. Przy zalewaniu żeliwa stwierdzono obecność wodoru. Jest ona widoczna zwłaszcza po drugiej stronie powłoki gazoprzepuszczalnej gdzie stężenie sięga powyżej 40%. Wydzielaniu wodoru towarzyszy wydzielanie się na powierzchni odlewu, znacznych ilości pyrolytycznego węgla. Stwierdzono, że gazy tworzące szczelinę są całkowicie wolne od tlenu.

### 1. Introduction

Full mold technology (FMC) has been used in the foundry industry since 1958, when H.F. Shroyer patented the essence of the process. A rapid development of this method occurred in the 80's, when it was used for the automotive applications (Ford, Fiat, Mitsubishi). The reason for interest in the FMC process is a significant reduction in production costs compared to the traditional methods of molding. For simple castings it amounts to 25%, while for complex shapes it reaches 40-45% [1]. This is due to the reduced cost of pattern manufacture, lower consumption of energy during molding and knocking out of castings, and reduced machining of the cast components. There is no need for the reclamation of molding sands. FMC, however, presents also a number of new technological problems. Pattern evaporation starts at about 500°C. The product of the decomposition is C<sub>8</sub>H<sub>8</sub> monomer which at higher temperatures undergoes a fragmentation producing lighter

hydrocarbons such as C<sub>7</sub>H<sub>6</sub>, C<sub>2</sub>H<sub>4</sub>, C<sub>2</sub>H<sub>2</sub>, and finally hydrogen as well as the lustrous carbon [2, 3]. M. Rossi et al. [2] found that the volume of gaseous products is highly dependent on temperature. At 750°C it amounts to 250cm<sup>3</sup>/g, while at 1300°C it raises up to 800cm<sup>3</sup>/g.

The quality of castings depends on the pouring rate which, in turn, is not determined arbitrarily by the process engineer, but results from the pattern evaporation rate and the rate at which products of pattern decomposition are removed from the mold cavity through a gas-permeable coating applied onto the pattern.

These relationships were analyzed in [3] and then in a series of publications by J. Pacyniak and R. Kaczorowski, who created a mathematical description of the process and through process simulation have determined the relationships that exist between the basic parameters [4,5,6,7]. Yet, of all the analyzed variables, only the development of a method for direct measurement of the coating permeability has ended in

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success. Attempts were also made to measure the gas pressure in a gap [3], but the results obtained were valid for low pouring rates only. This pressure controls the rate at which the metal column is raising in a mold cavity, and therefore it must be only slightly lower than the metallostatic pressure determined by the difference in metal levels in the down-gate and mold cavity. The measured maximum values do not exceed 4000 Pa [3], which corresponds to the silumin column height of about 15 cm. The aim of this paper has been verification of gas pressure measurements in the gap and in a layer of molding sand directly adjacent to the gap with the pouring height kept at a level of 25 cm. It was also decided to examine the hydrogen partial pressure, determining the decomposition degree of hydrocarbons that are released from the pattern during its evaporation.

## 2. Experimental Procedure

Tests were carried out on patterns made from the foamed polystyrene characterized by the following parameters:

- ♣ Density:  $\geq 35 \text{ kg/m}^3$
- ♣ Thermal conductivity:  $\lambda \leq 0.035 \text{ [W/mK]}$  (50-60 mm);  $0.036 \text{ [W/mK]}$  (80-120)
- ♣ Compressive stress at 10% longitudinal strain: CS (10/Y)  $500 \geq 500 \text{ [kPa]}$
- ♣ Creep in compression: CC (2/1.5/50)  $180 \geq 180 \text{ [kPa]}$
- ♣ Percent of closed cells :  $\geq 95 \text{ [%]}$
- ♣ Modulus of elasticity:  $20 \text{ [N/mm}^2\text{]}$
- ♣ Application temperature :  $\leq 70 \text{ [}^\circ\text{C]}$

Patterns were glued together from elements cut out from the foamed polystyrene plates. The elements were cut out by a thermal technique using heat-resistant wire in a numerically controlled plotter.

The shape of one pattern is shown in Figure 1.

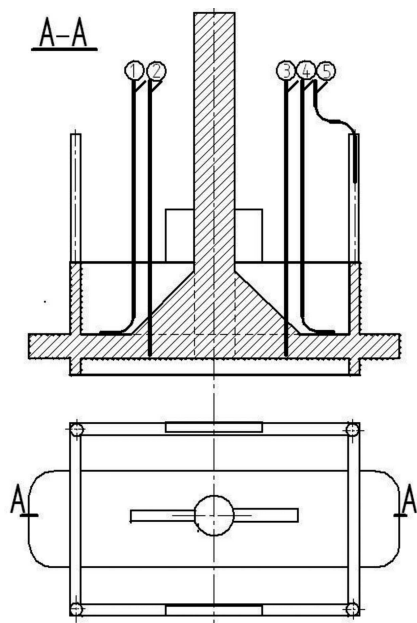


Fig. 1. The foamed polystyrene pattern. Copper tube with 0.5 mm holes, transporting the gas to the gauges measuring the pressure, content of oxygen and hydrogen, 1,4 – from molding material, 2,3 – from the gap between pattern and rising column of liquid alloy, 5 – from the flow off

Patterns were reinforced with gas-permeable Protecta WST coating.

Parameters of the coating were as follows:

- ♣ Density at  $20^\circ\text{C}$  –  $1.60\text{-}1.80 \text{ g/cm}^3$
- ♣ Dry matter content –  $65\text{-}75\%$  [8]

Coatings were applied onto patterns by dipping. The protective coating was prepared so that its conventional viscosity was 25s. The diluent was demineralized water. The conventional viscosity was measured with standard Ford cup with a  $\varnothing 4 \text{ mm}$  outflow diameter. The kinematic viscosity calculated from the flow time [8] was  $100 \text{ mm}^2/\text{s}$ . Drying of the coating deposited on a pattern took place in a drier with forced air flow at a temperature of  $65^\circ\text{C}$  maintained for a period from 40 minutes to one hour. The drying temperature was chosen in such a way as to avoid the pattern deformation. The first layer of coating was dry within 40 minutes. The drying time for patterns was one hour after each consecutive dipping operation. The thickness of the coating was 1 to 1,2 mm.

Patterns were molded in a dry mixture composed in 50% of 0.8 mm granulation grit from Bukowno and in 50% of Biała Góra sand with a granularity of 0.4 to 0.63 mm. Figure 2 shows a schematic diagram of mold ready for pouring.

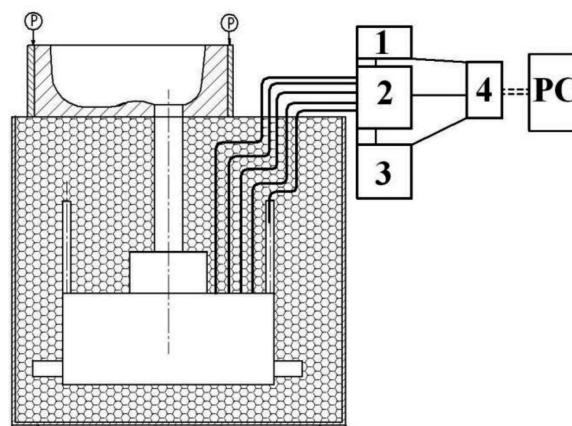


Fig. 2. Mold ready for pouring: 1 – differential pressure gauge, 2 – pellistor, 3 – zirconia cell, 4 – Agilent, PC – computer

Copper tubes with 0.5 mm holes were installed in the mold to operate as probes for the determination of gas pressure and hydrogen content in the gas in a gap formed between the pattern and the rising column of liquid alloy (1), and also in the layer of molding material contacting the gas-permeable layer (2). At the same points, Ni-NiCr (K type) thermocouples were provided for the measurement of temperature. Copper tubes were connected to a differential pressure gauge, pellistor measuring hydrogen content and zirconia cell for measure of the oxygen in the examined gaseous phase [9,10]. The indications of the measuring devices were recorded by an AGILENT 34970A recording unit.

## 3. Results

### 3.1. Pouring time

For the adopted height of the down-gate, the cross-sections of the gating system were selected in such a way as to ensure the mold filling time of 7 seconds. The overpressure

generated in mold prolongs the time of pouring, making calculation of the gating system impossible. The time was measured with a graph plotting temperature changes in the gap, in mold cavity and in the covered flow-off. Figures 3 and 4 show these changes.

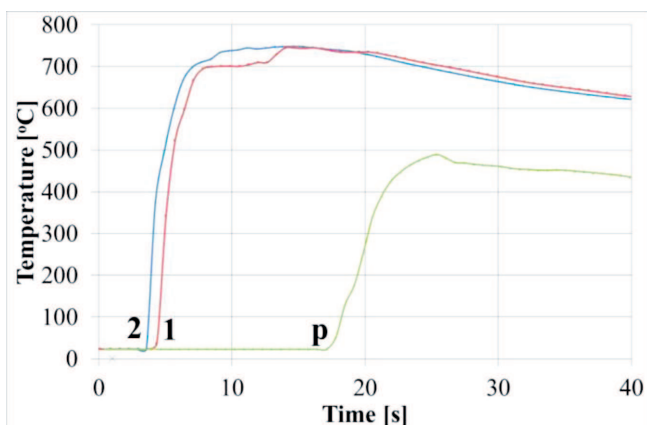


Fig. 3. Temperature changes in the gap produced during pouring of AK11 alloy: 1, 2 – casting, p – flow-off

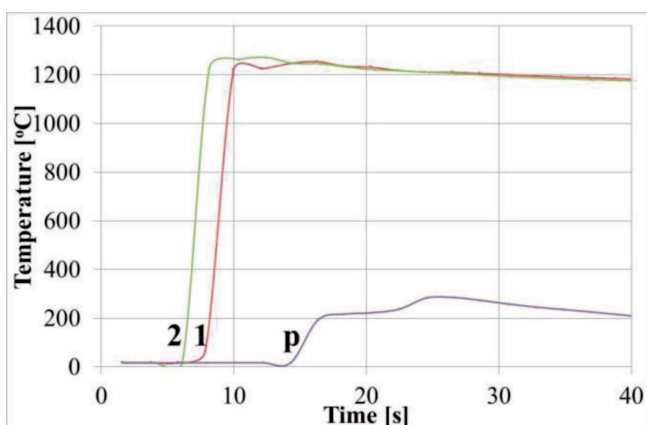


Fig. 4. Temperature changes in the gap produced during pouring of gray cast iron: 1, 2 – casting, p – flow-off

The time of pouring was determined as a lapse of time from the initial sudden increase of pressure in the gap until the stabilization of maximum temperature achieved during the process. It was estimated at a value of about 8 seconds for both the silumin and cast iron. The attempt to adopt as the end of pouring the moment of a marked increase of temperature in the flow-off ended in failure, mainly because of the fact that the flow-off was not completely filled with metal, probably due to a large drop of temperature at the already cold metal front (the difference in metal levels between the upper surface in the down-gate and in the top part of a covered flow-off was 15 cm).

Figure 5 shows changes of pressure in a gap between the pattern and the rising metal column observed for both the AK11 alloy and gray cast iron.

For a few seconds directly after the start of pouring, both pressure and temperature in the gap remain at the starting level. This time is used to remove (evaporate) the pattern of a gating system. When the mold cavity is reached, a typical gap is formed between the evaporating pattern and metal surface.

Pressure of gas in this gap increases rapidly and then stabilizes at a level close to balance. In the case of cast iron, the increase of pressure is slightly faster and achieves a level nearly 3 times higher. This is due to a larger volume of the evolving gas and higher metallostatic pressure of the metal column.

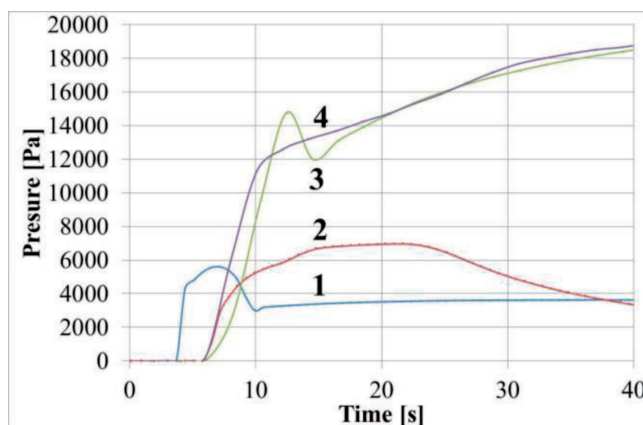


Fig. 5. Pressure changes in the gap during casting of silumin (1 and 2) and gray iron (3 and 4)

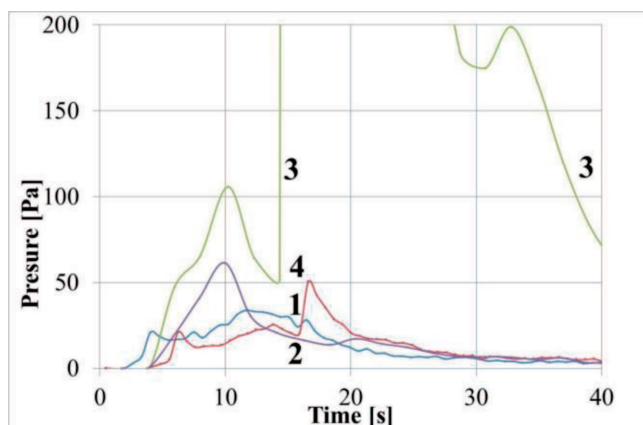


Fig. 6. Pressure of gas in the gap in the covered flow-off during casting of silumin (1 and 2) and gray iron (3 and 4)

In the covered flow-off, the pressure is much lower. Metal stops moving and acts as a piston. The size of the gap increases due to the progressing evaporation of a pattern material. In experiment no 4 (Figure 6) the flow-off has been filled and the pressure was comparable as in the gap in casting.

Figure 7 shows the measured values of pressure in the zone of molding material directly adjacent to the gas-permeable coating. This pressure is very low, and this fact is due to the limited permeability of coating and very high permeability of the coarse sand.

Figures 8 and 9 show changes of hydrogen concentration in gas, representative of the dissociation degree of hydrocarbons, which are the product of polystyrene decomposition.

It has been noted that when silumin was poured, the amount of hydrogen was very small – merely traces of this gas were detected in the gap. On the other hand, the high temperature of cast iron pouring speeded up the decomposition of hydrocarbons. A comparison of Figures 8 and 9 indicates that hydrogen more easily than other gases penetrates through the coating. Therefore, its percent content in the total volume

is much higher and in the case of cast iron reaches the level recorded only when bentonite-bonded green sand molds are used [9].

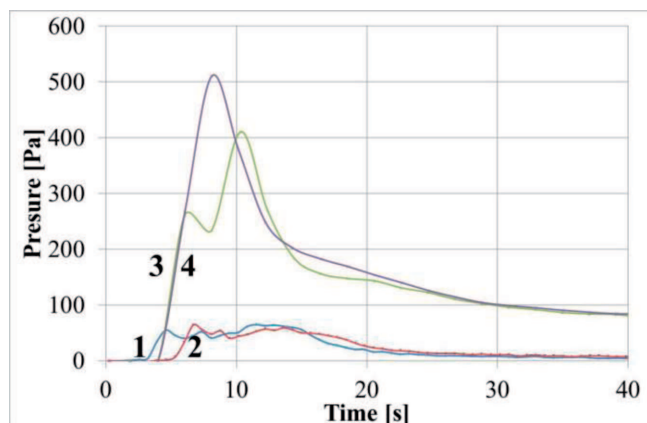


Fig. 7. Pressure of gas in mold in an area directly adjacent to the gas-permeable coating 1 and 2 – silumin, 3 and 4 – gray cast iron

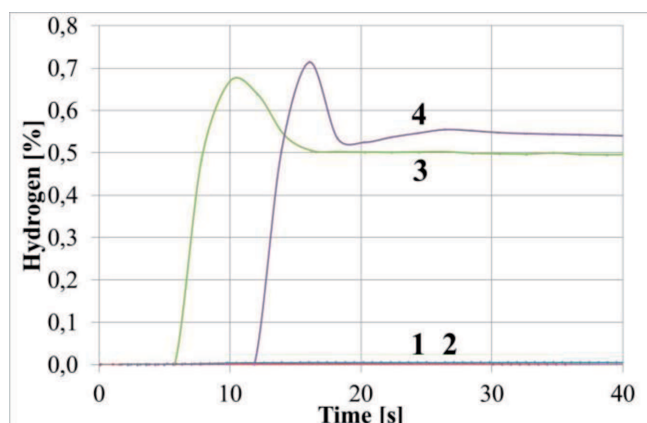


Fig. 8. Hydrogen concentration in gases filling the gap: 1 and 2 – silumin, 3 and 4 – cast iron

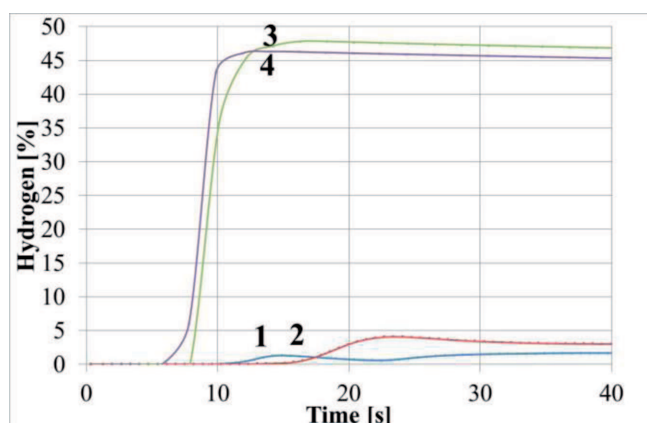


Fig. 9. Hydrogen concentration in molding material directly adjacent to the gas-permeable coating: 1 and 2 – silumin, 3 and 4 – cast iron

A fraction of the hydrogen content can be attributed to the decomposition of steam originating from moisture present in the coating.

When iron casting was poured, an attempt was made to determine the concentration of oxygen in the gap. The result

shown in Figure 10 indicates that the forming gap does not contain even trace amounts of oxygen.

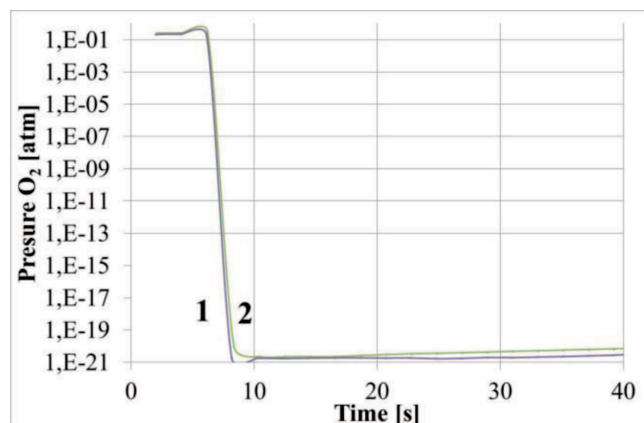


Fig. 10. Oxygen concentration in the gas gap

#### 4. Conclusions

The conducted studies lead to a conclusion that in the full mold casting process, the gases resulting from pattern evaporation create pressure of a value much higher than the value of pressure prevailing in mold cavity in a zone close to the gas-permeable coating. The values of this pressure are the higher, the higher is the temperature of pouring. Actual values of the pressure measured during casting were 6 and 14kPa for AK11 silumin and cast iron, respectively, and thus were higher than those found by Kaczorowski and co-authors [3]. The reason was probably the different height of pouring. However, the differences in pressure did not cause a significant difference in the rate of pouring in either of the two alloys, since the process of cast iron pouring was running at a higher metallostatic pressure.

The pressure increase in the gap occurs directly after the start of pouring; it reaches a maximum and either stabilizes or gently decreases as a result of the drop in metallostatic pressure.

The temperature of pouring has a significant effect on the decomposition rate of hydrocarbons evolving from the metal.

In pouring of cast iron, the presence of hydrogen was revealed. It was particularly evident across the gas-permeable coating, where its concentration reached a value of over 40%. This shows that of all the gases present in the gap it is mainly hydrogen that diffuses through the coating. It shows a high percent content in the trace amounts of gas sampled from the mold cavity. The evolution of hydrogen was accompanied by the evolution of large amounts of pyrolytic carbon on the casting surface.

When silumin was cast, only trace amounts of hydrogen were detected. It was found that gases forming in the gap contained no oxygen.

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