ARCHIVES
of
FOUNDRY ENGINEERING

ISSN (1897-3310)
Volume 7
Issue 2/2007
49– 52

10/2

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

Pattern evaporation process

Z. Żółkiewicz [a], M. Żółkiewicz [a]
[a] Foundry Research Institute, Zakopiańska Str. 73, 31 418 Kraków, Poland
* e-mail: kzs@iod.krakow.pl

Received 08.02.2007; Approved for print on: 12.03.2007

Abstract

The paper discusses the process of thermal evaporation of a foundry pattern. At several research-development centres, studies have been carried out to examine the physico-chemical phenomena that take place in foundry mould filled with polystyrene pattern when it is poured with molten metal. In the technique of evaporative patterns, the process of mould filling with molten metal (the said mould holding inside a polystyrene pattern) is interrelated with the process of thermal decomposition of this pattern. The transformation of an evaporative pattern (e.g. made from foamed polystyrene) from the solid into liquid and then gaseous state occurs as a result of the thermal effect that the liquid metal exerts onto this pattern. Consequently, at the liquid metal-pattern-mould phase boundary some physico-chemical phenomena take place, which until now have not been fully explained. When the pattern is evaporating, some solid and gaseous products are evolved, e.g. CO, CO_2, H_2, N_2, and hydrocarbons, e.g. styrene, toluene, ethane, methane, benzene [16, 23]. The process of polystyrene pattern evaporation in foundry mould under the effect of molten metal is of a very complex nature and depends on many different factors, still not fully investigated. The kinetics of pattern evaporation is also affected by the technological properties of foundry mould, e.g. permeability, thermophysical properties, parameters of the gating system, temperature of pouring, properties of pattern material, and the size of pattern-liquid metal contact surface.

Keywords : casting, pattern, pattern made of foamed polystyrene, temperature, gas.

1. Introduction

The technology of foamed polystyrene patterns thermally evaporated during manufacture of castings from ferrous alloys still finds numerous obstacles on the way to its full practical use. The degree of difficulty depends not only on the properties of the process itself, but also on the degree of pattern intricacy, mould properties, and quality requirements imposed on castings. One of the main parameters which decide about the correct run of the evaporative pattern process is the kinetics of the thermal decomposition of the foamed polystyrene pattern as well as the volume and pressure of gases which are evolving from this pattern. The thermal destruction of pattern and the gas evolution rate depend on the rate of pattern evaporation. The products of pattern destruction (gases) present in mould are collecting in the gas gap, thus raising the pressure of gases above the surface of molten metal.

The products of pattern evaporation are affecting not only the molten metal, but also the foamed polystyrene pattern and the mould cavity surface, specially the ceramic layer. The thermal destruction of pattern, including the evolution of gases from the evaporating polystyrene, is related with the evaporation rate of this pattern. The, evolving in mould, products of pattern destruction (gases) increase the pressure of gases above the surface of molten metal. The transport of gases from the mould to the outside is ensured by the mould permeability effect. This article presents the results of the investigations carried out to determine what impact the temperature has on the pattern evaporation process.

2. The process of foamed polystyrene pattern evaporation

At Sharf University in Teheran, the authors of [3] conducted simulations and experiments on the process of pouring and evaporation of pattern in a mould - the LFC process. The authors have adopted the assumption that the mathematical results of simulation will be checked during experiments. For simulation they used the 3D-VOF computer technique and ASOLA VOF

(SOLA – VOF) program. At the experimental stage, using a special 16 mm camera, they filmed the process of mould filling with metal.

Some algorithms were adopted along with a system of mathematical equations describing the process of liquid metal flow in mould and the, related with this effect, process of decomposition - thermal evaporation of the foamed polystyrene pattern.

The run of the process was described in the article. The authors adopted some algorithms and a system of mathematical operations to describe the molten metal flow in mould and the, related with this effect, process of decomposition - thermal evaporation of the foamed polystyrene pattern.

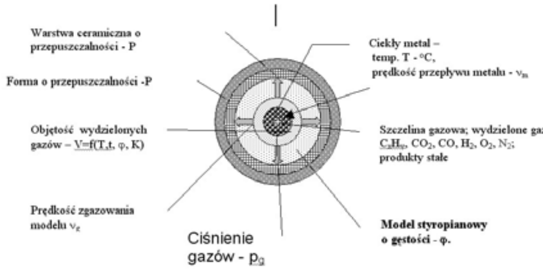

Fig. 1. Schematic representation of the process of thermally evaporated patterns

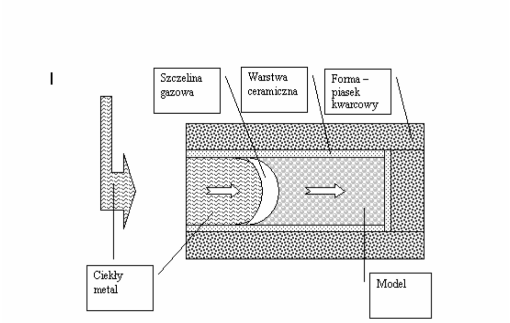

Fig. 2. Schematic representation of the pouring process [7-11]

Some algorithms were adopted along with a system of mathematical equations describing the process of liquid metal flow in mould and the, related with this effect, process of decomposition - thermal evaporation of the foamed polystyrene pattern.

The simulation of mould filling process, when the mould is holding an evaporative pattern, was recorded, taking into account the equilibrium of mass and energy.

The instantaneous transport was recorded by the following equation:

$$\frac{D\vec{V}}{Dt} = \frac{\nabla P}{\rho} + g + \nu \nabla^2 \vec{V} \quad (1)$$

where: C_p – thermal capacity,
e - thickness of layer (coating),
F – fraction (fragment) of volume, partial volume,
g – acceleration of gravity,
P - pressure,
T – temperature,
t – time,
V_{gap} – gap volume,
V_{gas} – gas volume,
ρ – density, mass density,
υ– coefficient of kinematic viscosity

Investigations conducted by W.S. Szuljak and others [4] have indicated that thermal evaporation of foamed polystyrene pattern is proceeding together with evolution of products in the gaseous, liquid and solid state. An interrelation between them depends on the temperature of liquid metal and on pattern properties.

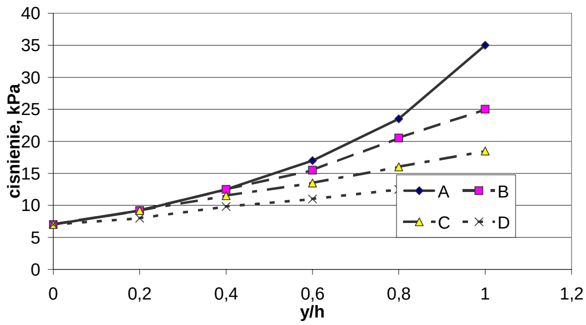

Fig. 3. Pressure of gas evolving from the evaporative pattern EPS in function of the distance from ingate for vertical shapes A, B, C, D [3]

Figure 2 shows the curve that divides the gas evolution rate into two intervals. Interval I covers the gas volume Q_I evolved during pouring of mould with liquid metal. Interval II covers the gas volume originating from the decomposition of a liquid phase, which is present at the metal – pattern interface. The ratio of Q_I to the gas volume evolved during complete evaporation of pattern Q_o determines the degree of a polystyrene pattern evaporation n ($n = Q_I / Q_o$). With n = 1, the pattern in fully evaporated. Knowing the value of coefficient n, the coefficient of the liquid phase is calculated $\varepsilon = 1 - n$.

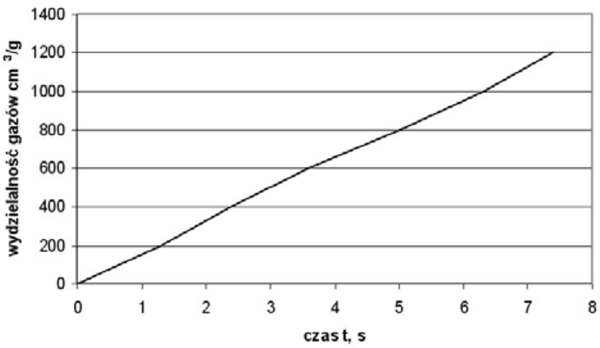

Fig. 4. Gas pressure changing in function of the EPS pattern mass [3]

Analysis also covers the effect of negative pressure created in mould cavity on the system of forces affecting the side surfaces of mould. The condition of making sound castings is preserving the state of equilibrium between the forces acting onto the side surfaces of mould in the gas gap created above the surface of molten metal. Recording the system of forces resulting from different pressures in mould, in gas gap and in metal column, it was observed that at some levels, the conditions in mould are formed which promote deformation of the mould pouring system.

The simulation of the pattern evaporation process was carried out and mathematically described by V. Bertman and others [2]. For analysis, the following parameters were adopted: density, time, pressure, coefficient of absolute viscosity. The process was described for a plate of 200x100 mm dimensions. A relationship was described between the volume of evolved gases and metal volume.

The mathematical description of the pattern evaporation process and metal flow in mould (simulation) according to Mirbagheri S.M. and others [3] covers on one side of the equation the change in gas volume in time DV/Dt, and on the other - a ratio of gas pressure change to the specific gravity of pattern (density) $\Delta P/\rho$ allowing in the equation for the following parameters: earth gravity g, evaporation rate ν and second power of change in gas volume $\Delta^2(\nu)$. The instantaneous transport (flow of a metal volume) was described by equation:

$$DV/Dt = -\Delta P/\rho + g + \nu\Delta^2(V) \qquad (2)$$

where:
ΔP – change of pressure,
ρ – pattern specific density,
g – acceleration of gravity,
ν – coefficient of kinematic viscosity,
V – velocity (axis y).
The condition of polystyrene pattern set in mould on pouring of this mould with metal and the course of the evaporation process were described by Shinsky O. I. For complete description of the process, specifically in the case of castings of intricate shapes, with variable cross-sections and different wall thicknesses, the problem should be considered in terms of the hydrodynamics of metal flow and of the process of pattern evaporation.

An important problem is knowing and defining the effect of the variable mould cross-sections on the kinetics of changes proceeding in mould, the rate of mould filling with metal, and the rate of metal surface rising in mould W_1. The main requirement
for obtaining a casting free from defects is satisfying the condition described by the following equation:

$$W1 = (0{,}8 \div 1{,}2)\, W_1^1. \qquad (3)$$

where: W_1^1 is optimum velocity.

Bakhtiyarov S.I., Overfelt R.A., Alagaramy A. from the University of Alabama [1] described the degradation process of polystyrene at different temperatures and different rates of metal flow. They determined the gas pressure in relation of a distance from the ingate.

The authors of [7-11] conducted at the Foundry Research Instiute in Kraków a number of investigations, the main aim of which was determination of a number of physico-chemical relationships; among others, the kinetics of the evaporation process was determined.

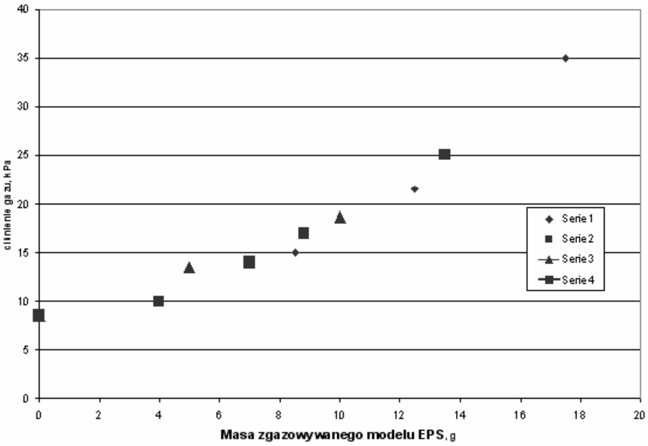

Fig. 5. The curve dividing the gas evolution rates during pouring of mould filled with polystyrene pattern; the cast metal (steel) temperature 1550°C (interval I- above the curve, interval II – below the curve) [2]

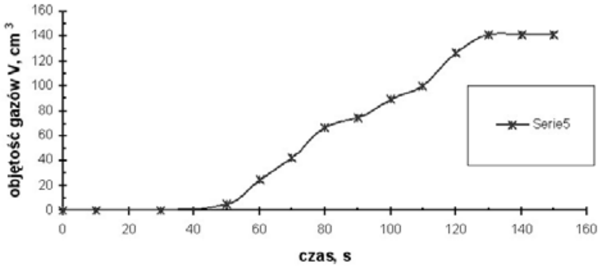

Fig. 6. Gas volume evolved from 1 g of the polystyrene pattern of 40 kg/m³ density at a temperature of 600°C in function of time [7-11]

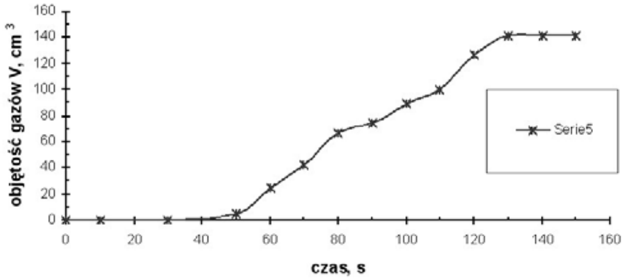

Fig. 7. Gas volume evolved from 1 g of the polystyrene pattern of 35 kg/m³ density in function of temperature [7-11].

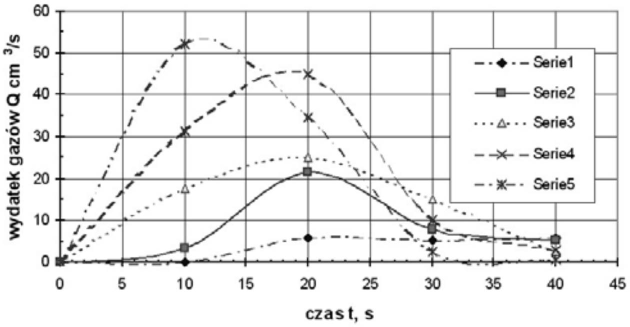

Fig. 8. Time interval within which a maximum gas volume Q evolves from the pattern of 20 kg/m^3 density evaporating at a temperature of 800°C –series 1, 900°C – series 2, 1000°C – series 3,1100°C – series 4, 1200°C – series 5, [7-11]

The diagrams show the evolved gas volumes and gas evolution rates obained for the polystyrene patterns of various densities.

3. Summary

From investigations described in [7-11] and data given in the literature it follows that temperature influences in a significant way the time of the foamed polystyrene pattern evaporation, the gas volume and the type and percent content of the gaseous products of the thermal decomposition of this pattern (Figures 20 to 41). From the presented data (Figures 30 to 32, 42, 43, 45) one can observe a relationship between the time of pattern evaporation and temperature t(T). At high temperatures, the pattern evaporates in a time very short, contrary to low temperatures when the process of its evaporation occurs slowly and in a time relatively long. On the other hand, from Figure 41 one can conclude that maximum gas evolution rate at the investigated temperature occurs in the time interval which does not exceed 20 s. After this time, the process of polystyrene pattern evaporation is proceeding with decreasing volume of the evolving gases. After the lapse of 25 s the gas evolution Q is decreasing all the time and is prone to reach zero; these are the times of the visible maximum.

References

[1] Bakhtiyarov S.I., Overfelt R.A., Alagaramy A.: Mesaurements of Decomposed EPS Gases Pressure and Molten Metal-polymeric foam Interface Velocity during Counter Gravity Lost Foam Casting. AFS Transaction, April 28-May 1, 2001, May 4 – May 7, 2002, p 1439 –

[2] Bertman V., Poliakov S., Hartman R.: Simulation der Giessformfullung unter Berucksichtigung des Gasdruckes. Giesserei 52, (2000) no. 3, p. 95 – 99,

[3] Mirbagheri S.M. et al.: International Journal of Cast Metals Research, 2003 v. 16, no. 6, p. 554,

[4] Molibog T. V.: Degradation of Expanded Polystyrene Pattern. AFS Transaction (02-101), April 28-May 1, 2001, May 4 – May 7, 2002, p. 1483 – 1496,

[5] Šuljak V.S.: Sostoianie lit'ja po gazificiruemym modeljam za rubiezom (Odlewanie technologią modeli zgazowanych za granicą), Litejnoe Proizvodstvo 1991, nr 1, s. 21 – 23,

[6] Wilk J., Żółkiewicz Z.: Determination of optimum Technology in Respect of the Required Values of Casting Quality Parameters by Aplication of the Weighted Variables Metric. Materials Enginering, Slovakia 2006, t.13, nr. 3, s. 89,

[7] Żółkiewicz Z.. Żółkiewicz M., Jankowski W., Wilk J.: Sterowanie procesem krzepnięcia odlewu w technologii modeli cieplnie zgazowywanych. Archives of Foundry – Archiwum Odlewnictwa 2006, rocznik 6, nr 18 ref. 119/18 s..219,

[8] Żółkiewicz Z., Jankowski W.: Effect of temperature on the evaporation time of foamed polystyrene pattern. Acta Metallurgica Slovaca 7, 2001, nr.3 (1/2), s.309 – 314,

[9] Żółkiewicz Z., Jankowski W.: Effect of the density on the rate of gas emission from polystyrene pattern in the lost foam process. PAN, Krzepnięcie Metali i Stopów, Rocznik 43, 2000, nr 2, referat 43/63 s. 553 – 560,

[10] Żółkiewicz Z., Jankowski W.: Vliv teploty na rychlost uvolnovani plynu z polystyrenovych modelu pri postupu liti do plnych forem, Slevarenstvi 2000, Vol.XLVIII, nr 4, s.192–194,

[11] Żółkiewicz Z., Jankowski W., Wacławik Z.: Effect of temperature on the volume and rate of gas emissions from polystyrene pattern evaporated in the full mould process. Archives of Metallurgy, Kraków 1999, t.44, nr.1, s. 111 – 118.