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FILLING THE MODEL DIE CASTING MOULD – ANALYSIS BY MEANS OF THE LEICA QWIN 2.2 PROGRAM

ANALIZA ZAPEŁNIENIA MODELOWEJ FORMY CIŚNIENIOWEJ ZA POMOCĄ PROGRAMU LEICA QWIN 2.2

The problem of broadly understood model investigations of the die casting process is one of the current research subjects undertaken by the Faculty of Foundry Engineering together with the Department of Process Automation of the Faculty of Mechanical Engineering and Robotics of AGH, University of Science and Technology. The undertaken research is aimed on elaboration of mathematical model of die cavity filling process in accordance with geometric features of modelled casting, and its gating system able to reduce the molten metal stream dispersion degree in cold chamber die-casting machine.

The LEICA QWIN V. 2.2. program for the automatic image analysis was applied for measuring the area taken up by liquid during filling the flat mould in the model system of die casting cold-box machine. Utilizing the recording, obtained by means of filming the model moulds filling, which enabled the analysis of the mould cavity filling degree, realised at various injection velocities the suitability of the LEICA QWin v. 2.2. program for the automatic image analysis (for the rectangular model mould, gate hole 4.7 x 48 mm, two venting modes and two viscosities of model liquid) was verified.

Keywords: die casting, mould filling, model investigations, LEICA QWin v. 2.2 Program

Zagadnienie szeroko rozumianych badań modelowych procesu odlewania ciśnieniowego jest jednym z aktualnych, tematów badawczych prowadzonych na Wydziale Odlewnictwa wspólnie z Katedrą Automatyzacji Procesów na Wydziale Inżynierii mechanicznej i Robotyki Akademii Górniczo-Hutniczej w Krakowie. Realizowany wspólnie program badań modelowych, ma na celu opracowanie opisu matematycznego procesu zapełniania wnęki formy ciśnieniowej adekwatnego do geometrycznej charakterystyki modelowanego odlewu oraz jego systemu zasilania, zdolnego do ograniczenia zjawiska rozpraszania dyspersyjnego strugi metalu w zimnokomorowych maszynach ciśnieniowych.

Program LEICA QWIN V. 2.2. do automatycznej analizy obrazu zastosowano do pomiarów powierzchni zajętej przez ciecz w trakcie zapełniania płaskiej formy w modelowym układzie maszyny ciśnieniowej zimnokomorowej. Wykorzystując rejestrację procesu zapełniania badanych form modelowych za pomocą filmowania, która umożliwiła analizę stopnia zapełnienia wnęki formy, realizowanego przy różnych prędkościach wtrysku sprawdzono przydatność programu LEICA QWin v. 2.2. do automatycznej analizy obrazu dla prostopadłościennej formy modelowej, dla szczeliny wlewowej 4,7 x 48 mm, dwóch sposobów odpowietrzenia i dwóch lepkości cieczy modelowej.

1. Experimental stand

The experimental stand for model testing of the die casting process and the physical model of the pressing system were presented in papers [3, 5]. The following systems are included in the experimental stand:

- Physical model of a die mould,
- Physical model of a shot sleeve,
- Electro-hydraulic steering system,
- Hydraulic feeder.

In model investigations presented in reference [1] the physical model of the die mould with a rectangular cavity of external dimensions: 280 mm (height) x 190 mm (width) x 10 mm (depth) was used. Moulds models of 3 versions of the mould cavity were made:

- Rectangular cavity- version I,
- Rectangular cavity with 2 circular inner elements – version II,
- Rectangular cavity with 2 inner elements of a half-ring shape – version III.

The view of the individual tested moulds is presented in Figure 1.

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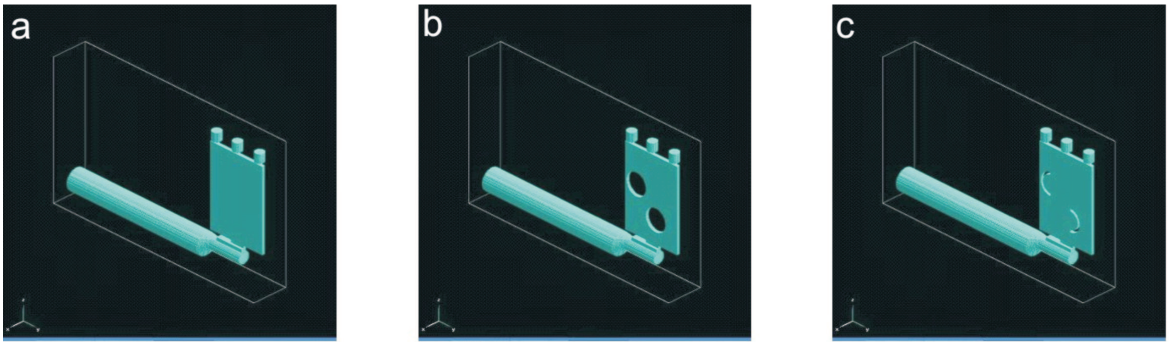

Fig. 1. Fig. 1. View of tested experimental moulds; a) Mould version I, external dimensions of mould cavity: 280×190×10 mm, mould volume V_f = 0.532 dm^3, b) Mould version II, mould volume V_f = 0.441 dm^3, c) Mould version III, mould volume, V_f=0.456 dm^3

Each mould version had venting openings on the upper surface. The following markings were used for venting modes in the presented tests:
O-O-O – full venting – total surface of venting openings 52 mm^2, venting degree 2.73%,
Z-O-Z – reduced venting – total surface of venting openings 8 mm^2, venting degree 0.47%.

2. Measuring method

Two Newtonian fluids of a different viscosity and density obtained by the appropriate dilution of glycerine by distilled water were used as model liquids. The presented investigations were performed for the model liquid of a kinematic viscosity equal $1.39 \cdot 10^{-6}$ m^2/s (1.39 cSt) – marked: "LIQUID 7%", which approximately corresponds to the viscosity of aluminium alloys at die casting. The second liquid had viscosity $9.46 \cdot 10^{-6}$ m^2/s (9.46 cSt) – marked: "LIQUID 80%", can represent viscosity similar to the one of other aluminium alloys at casting in a state of partial crystallisation known as SSM (Semi Solid Metal).

The method of digital recording with a rate of 30 frames per second was applied for the recording of flow effects occurring during a mould filling [1].

Transparent elements of instrumentation applied in tests and liquids allowed for the observation and recording of flow effects, which created a new assessment possibility of a flow character, independent of the Reynolds number. Applying, described in papers [2, 3], the recording of the model moulds filling by means of filming, the analysis of the filling degree of the mould cavity as a function of time at various liquid injection velocities, was performed. The filling degree of the mould cavity was also performed – in analogical conditions – by measuring the occupied surface by means of the LEICA QWin v. 2.2. program for the automatic image analysis [1, 7].

3. The obtained results

The presented investigations were performed for the model mould, version I – III, for the filling hole 4.7×48 mm, two modes of ventilation and two viscosities of the model liquid. The example of a single frames of the filling process filming for model liquid marked "LIQUID 7%" and venting mode O-O-O is shown in Fig. 2, while in Fig. 3 the result of its plane map obtained by the LEICA QWin v. 2.2 program.

Analogous situation is shown in Fig. 4 and 5, where a three single frames of the filling process filming for model liquid marked "LIQUID 80%" and venting mode Z-O-Z are combined with the results of their plane map obtained by the LEICA QWin v. 2.2 program.

The results of surface area measurements made by the LEICA QWin v. 2.2 microscope are presented in Figs. 6-8.

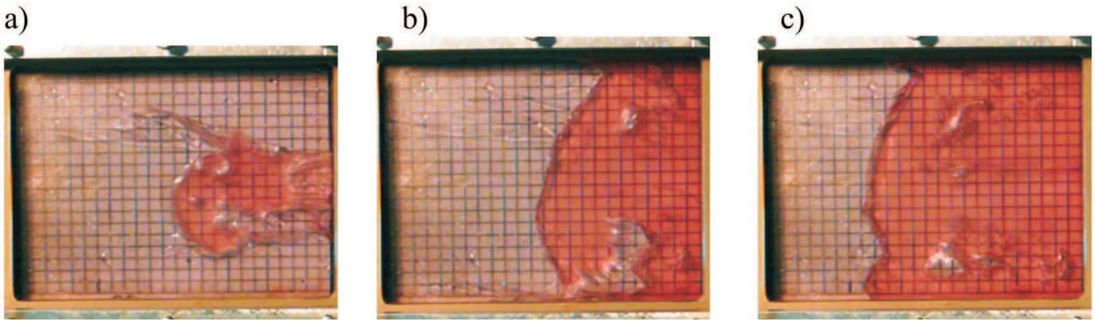

Fig. 2. Single frames of the filling process filming. Version I, model liquid: "LIQUID 7%", filling time: a) τ = 0,26(6) s, b) τ = 0,66(6) s, c) τ = 1,0 s; plunger velocity v_p = 0.08 [m/s]; full venting mode O-O-O (52 mm^2, venting degree 2.73%). Mould drawing turned 90 degrees to the left in relation to the actual working position [1]

Fig. 3. Plane map of the single frames picture from Fig. 2, after the image analysis made by LEICA Qwin v. 2.2.program

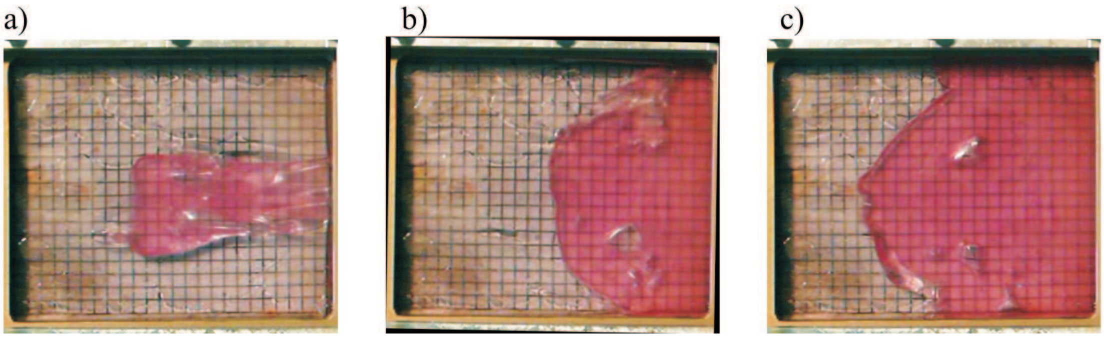

Fig. 4. Single frames of the filling process filming. Version I, model liquid: "LIQUID 80%", filling time: a) τ = 0,26(6) s, b)τ = 0,66(6) s, c)τ = 1,0 s; plunger velocity v_p = 0.08 [m/s]; **Z-O-Z** – reduced venting mode (surface of venting openings 8 mm^2, venting degree 0.47%). Mould drawing turned 90 degrees to the left in relation to the actual working position [1]

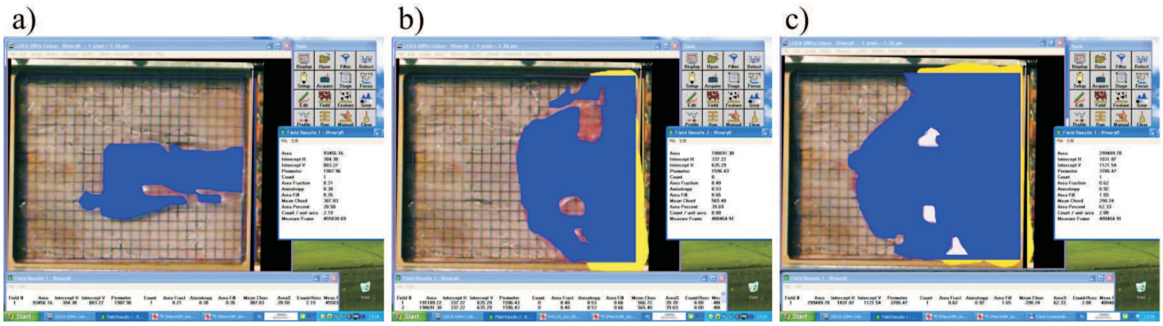

Fig. 5. Plane map of the single frame pictures from Fig. 4, after the image analysis made by LEICA Qwin v. 2.2.program

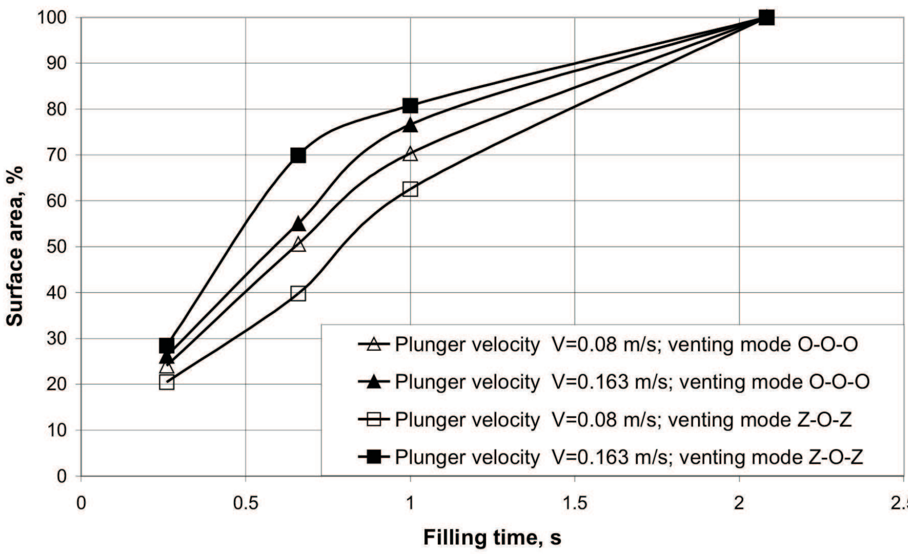

Fig. 6. Surface areas taken up by "LIQUID 80%"vs. filling time, calculated by means of the LEICA QWin v. 2.2 program, version I of the mould [1, 7]

The analysis of data indicates a much more intensive evolution of a stream surface in the case of using the model liquid: "LIQUID 7%" of a lower viscosity as compared with: "LIQUID 80%". This indirectly points out a higher mobility and an inclination for turbulences of the liquid of a lower viscosity.

The cavity filling process of the moulg version I at total venting (O-O-O) and at reduced venting (Z-O-Z) are marked in Fig. 6 for version I of the mould and "LIQUID 80%". Analogous data for model liquid "LIQUID 7%" are given in Fig. 7.

A more significant influence of venting on the cavity filling degree by the model liquid of a lower viscosity can be observed.

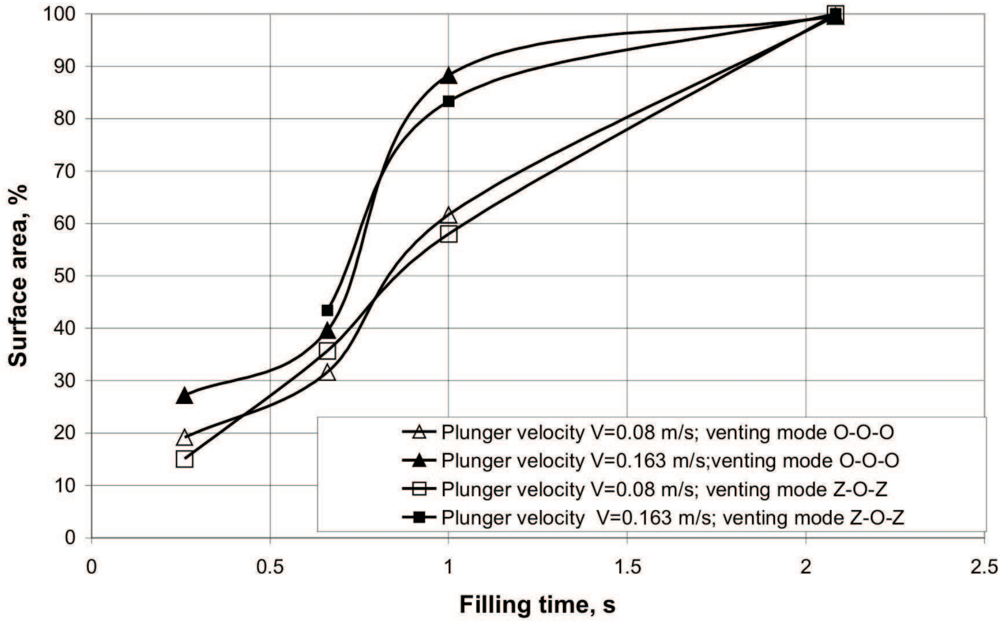

Fig. 7. Surface areas taken up by "LIQUID 7%" vs. filling time, calculated by means of the LEICA QWin v. 2.2 program, version I of the mould [1]

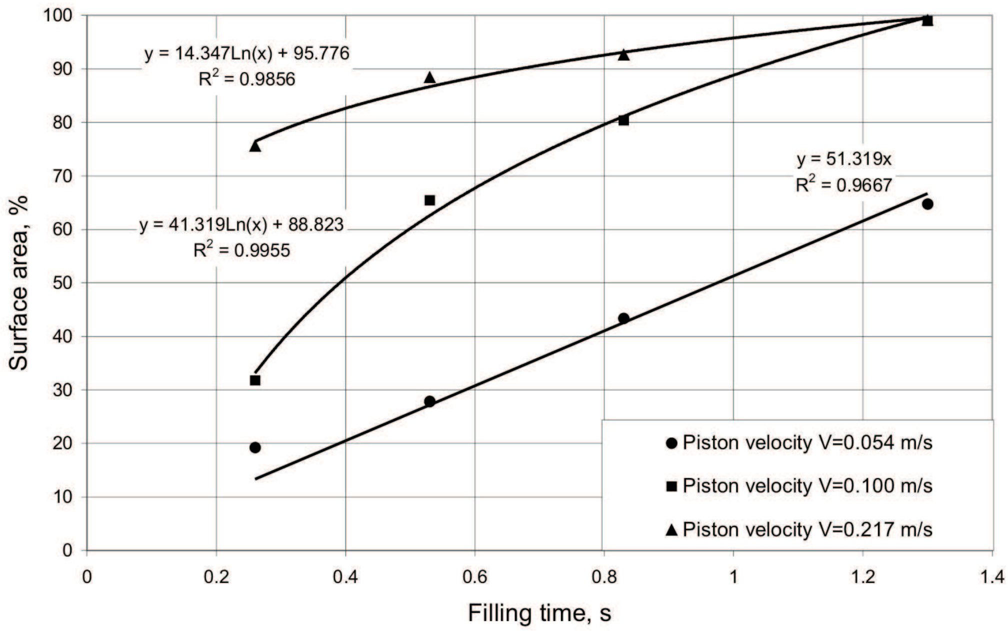

Fig. 8. Surface areas taken up by "LIQUID 80%" vs. filling time, calculated by means of the LEICA QWin v. 2.2 program, version III of the mould, venting mode O-O-O

4. Analysis and interpretation of the obtained results

It can be pointed out that the ratio of the instantaneous liquid volume $V^{(\tau)}$ to the total cavity volume V_{total} fulfils the condition:

$$\frac{V_{(\tau)}}{V_{total}} = \frac{F_{(\tau)} \cdot g_{(\tau)}}{F_{total} \cdot g} = \frac{Q_{act(\tau)} \cdot \tau_{(\tau)}}{Q_{act} \cdot \tau_z} \quad (1)$$

where:

$F_{(t)}$ and F_{total} – surface of the mould cavity taken up by liquid metal (calculated by the LEICA QWin v. 2.2 program) and the total observed surface [m^2] – respectively,

$Q_{act(t)}$ and Q_{act} – actual volumetric rate of filling instantaneous and average [m^3/s] – respectively,

$k = g_{(t)}/g$ – quotient of the actual thickness of the liquid layer $g_{(t)}$ and the depth (thickness) of the mould cavity (g) – which means the filling degree of the mould cavity cross-section,

$\tau_{(\tau)}$ and τ_z – current and the total filling time determined by filming [s].

It can be assumed, that for the given conditions of the mould filling, its instantaneous ($Q_{act(t)}$) and average value (Q_{act}) are equal to each other, and Eq. (1) can be presented in the form allowing to combine the interesting quantities:

$$\frac{F_{(\tau)}}{F_{total}} \cdot k = \frac{\tau_{(\tau)}}{\tau_z} \quad (2)$$

Quotient k is determined by:

$$k = 1 - \varepsilon = \frac{\tau_{(\tau)}}{\tau_z} \cdot \frac{F_{total}}{F_{(\tau)}} \quad (3)$$

The velocity of the model liquid (υ_{cwlew}) at the cavity gate was determined from the equation:

$$v_{total} = v_p \cdot \frac{F_{sleeve}}{F_{gate}}; \quad \text{m/s} \quad (4)$$

where: F_{sleeve}, F_{gate} – surface of the shot sleeve and the mould filling gate [m^2] – respectively, υ_p – average velocity of a plunger, [m/s].

The actual volumetric rate of filling, determined on the basis of the cavity filling times by liquids of the determined viscosity is listed in Table 2.

The relation between the instantaneous apparent density of the mixture liquid – air, physical density of the liquid phase and porosity of the mixture are given by the following equations:

$$\rho_{(\tau)} = \rho_f \cdot (1 - \varepsilon) = \rho_f \cdot k = \rho_f \cdot \frac{\tau_{(\tau)}}{\tau_z} \cdot \frac{F_{total}}{F_{(\tau)}} \quad (5)$$

$$\varepsilon = 1 - k = 1 - \frac{\tau_{(\tau)}}{\tau_z} \cdot \frac{F_{total}}{F_{(\tau)}} \quad (6)$$

The expression 'a dispersion of a model liquid stream' occurs in problems concerning filling of the mould cavity at die casting. According to the definition the value of this expression is the ratio of the surface of the liquid to its volume. It can be assumed, in simplification, that in a flat system – in practice two dimensional – the measure of the expansion surface is the ratio of the scanned liquid surface ($F_{(t)}$) to the observed surface $F_{całk}$ (240×190×10 mm), in a similar fashion as given in Equation (2). Denoting by D_D – dispersion degree of the liquid stream in the mould cavity, by $F_{(t)}$ – surface determined by means of the LEICA QWin v. 2.2 program, by $V_{(\tau)}$ instantaneous, geometric volume of the liquid, and by V_{act} – its actual volume, the equation for the dispersion degree can be written as:

$$D_D = \frac{F_{(t)}}{V_{act(t)}} = \frac{F_{(t)}}{V_{(t)} \cdot (1 - \varepsilon)} = \frac{F_{(t)}}{F_{(t)} \cdot (1 - \varepsilon) \cdot g} = \frac{1}{k \cdot g}; \quad \text{[1/cm]} \quad (7)$$

or – when taking into account equations (3), (5) and (6)

$$D_D = \frac{F_{(t)}}{V_{act(t)}} = \frac{1}{k \cdot (1 - \varepsilon)} = \frac{\rho_f}{\rho_{(t)} \cdot k}; \quad \text{[1/cm]} \quad (8)$$

The calculation performed, as an example, for data contained in Table 1 indicates, that in the range of obtained values for k = 0.44 – 1.0 value of D_D = 2.27 – 1.0 [1/cm], which means that only at the very beginning of filling (when there is a full swelling of a liquid in the shot sleeve) and when liquid is fully forced through to venting channels its density is equal or nearly equal the nominal values. In the remaining time we are dealing with a mixture of phases: model liquid – air of a dispersion degree higher than unity, characterising the presence of dispersed gas bubbles.

The fragment of calculations of factors k, ρ(t)ε for data obtained from the process film analysis and by means of the LEICA QWin v. 2.2 program is presented in Table 1.

5. Conclusions

An assessment of suitability of the LEICA QWin v. 2.2. program for automatic image analysis in investigations of flow effects requires taking into account the fact that the degree of covering a flat surface of mould cavity by liquid – recorded by this method – does not inform about the thickness of this

TABLE 1

The values of factors k, ρ(t),ε determined on the basis of the surface area measurement using the LEICA QWin v. 2.2 program and the actual volumetric rate of filling by the model liquid – determined by filming. Filling gate 4.7×48 mm, venting area F_{vent} = 52 mm^2 for venting mode O - O - O and F_{vent} = 8 mm^2 for reduced venting mode Z -O -Z

Parameters	Surface area taken up by model liquid [%] determined by using LeicaQWin v. 2.2 program								
Model mould	Version I of the model mould								
Filling time [s]:	0,26(6)			1,00			2,083		
Value of tested factor	k	$\rho_{(t)}$	ε	k	$\rho_{(t)}$	ε	k	$\rho_{(t)}$	ε
v_p =0.08 [m/s]; venting mode O-O-O; "LIQUID 7%"	0.66	0.77	0.77	0.77	0.79	0.22	1.00	1,01	0.00
v_p=0,163 [m/s]; venting mode O-O-O; "LIQUID 7%"	0.47	0.54	0.54	0.54	0.55	0.46	1.00	1,01	0.00
v_p=0,08 [m/s]; venting mode O-O-O; "LIQUID 80%"	0.53	0.68	0.68	0.68	0.83	0.32	1.00	1,21	0.00
v_p=0,163 [m/s]; venting mode O-O-O; "LIQUID 80%"	0.49	0.63	0.63	0.63	0.76	0.37	1.00	1,209	0.00
v_p=0,08 [m/s]; venting mode Z-O-Z; "LIQUID 7%"	0.85	0.83	0.83	0.83	0.84	0.17	1.00	1,015	0.00
v_p=0,163 [m/s]; venting mode Z-O-Z; "LIQUID 7%"	–	0.58	0.58	0.58	0.58	0.42	1.00	1,01	0.00
v_p=0,08 [m/s]; venting mode Z-O-Z; "LIQUID 80%"	0.62	0.77	0.77	0.77	0.93	0.23	1.00	1,21	0.00
v_p=0,163 [m/s]; venting mode Z-O-Z; "LIQUID 80%"	0.45	0.59	0.59	0.59	0.72	0.41	1.00	1,21	0.00

TABLE 2

The list of empiric formulas for the determination of the actual volumetric rate of model liquid during filling – mould versions I-III – experiment concerns different model liquids, venting modes and velocities in filling gate. Shot sleeve filling degree 50% (φ = 0.5)

Actual average volumetric rate of filling determined by filming Q_{film} [cm^3/s].	
Average volumetric rate of filling by model liquid "LIQUID 80%"	
Venting mode O-O-O; 4.7×48 mm	$Q_{act} = -23,732\, v_{total}^2 + 239{,}12\, v_{total}$; $R^2 = 0{,}99$
Venting mode O-O-O; 3,0×48 mm	$Q_{act} = -12{,}748\, v_{total}^2 + 163{,}24\, v_{total}$; $R^2 = 0{,}99$
Venting mode Z-O-Z; 4,7×48 mm	$Q_{act} = -23{,}121\, v_{total}^2 + 221{,}7\, v_{total}$; $R^2 = 0{,}99$
Venting mode Z-O-Z; 3,0×48 mm	$Q_{act} = -10{,}112\, v_{total}^2 + 131{,}7\, v_{total}$; $R^2 = 0{,}98$
Average volumetric range of filling by model liquid "LIQUID 7%"	
Venting mode O-O-O; 4,7×48 mm	$Q_{act} = -18{,}48\, v_{total}^2 + 181{,}21\, v_{total}$; $R^2 = 0{,}99$
Venting mode O-O-O; 3,0×48 mm	$Q_{act} = -12{,}697 v_{total}^2 + 153{,}83\, v_{total}$; $R^2 = 0{,}99$
Venting mode Z-O-Z; 4,7×48 mm	$Q_{act} = -20{,}198\, v_{total}^2 + 178{,}99\, v_{total}$; $R^2 = 0{,}98$
Venting mode Z-O-Z; 3,0×48 mm	$Q_{act} = -9{,}15\, v_{total}^2 + 117{,}27\, v_{total}$; $R^2 = 0{,}99$

liquid layer (under the given area), what is essential for the determination of the actual volumetric, or mass, rate of filling. In the case of thin-walled moulds, fulfilling in practice the two-dimensional condition, the applicability of the method is doubtless.

The condition for the proper using of this method is the simultaneous application of the filming method for the time of the filling process determination. This allows to determine not only the area but also the volumetric concentration of the model liquid stream being introduced into the mould, thus enabling the determination of instantaneous density of the two-phase mixture liquid-air ($\rho_{(\tau)}$), its porosity ($\varepsilon_{(\tau)}$) and dispersion degree D_D.

As results from the given data, the thickness of the filmed stream calculated on the basis of the surface scanned by the LEICA QWin v. 2.2. program and reduced to the initial liquid density is of a lower value than the mould cavity depth. At the process end the calculated liquid density increases to the nominal value.

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