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Experiments on the Model Testing of the 2nd Phase of Die Casting Process Compared with the Results of Numerical Simulation

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Abstract

Experiments of filling the model moulds cavity of various inner shapes inserted in rectangular cavity of the casting die (dimensions: 280 mm (height) x 190 mm (width) x 10 mm (depth) by applying model liquids of various density and viscosity are presented in the paper. Influence of die venting as well as inlet system area and inlet velocity on the volumetric rate of filling of the model liquid – achieved by means of filming the process in the system of a cold-chamber casting die was tested. Experiments compared with the results of simulation performed by means of the calculation module Novacast (Novaflow&Solid) for the selected various casting conditions – are also presented in the paper.

Keywords: Diecasting process, Model testing, Physical experiments, Computer simulation

1. Introduction

First works concerning the theory of filling a casting mould with metal in die casting processes were performed in years 1930-1950 by L. Frommer [1], who – as the first scientist - developed the theoretical basis of a liquid metal movement in a die casting. Later works, often mutually contradicting, constituted a trial of an experimental verification of the Frommer's theory. Finally his theory was recognized as the first successful test of determining the isothermal model of filling the mould with molten metal.
Maintaining the inlet velocity at 0,3 – 0,5 m/s in the conventional technology of low pressure die casting, leads to stable and planned filling of the casting die – found the authors of the paper [2]. However, due to a relatively low inlet velocity this process is not suitable for production of thin-walled castings, because during a fast casting solidification there is a possibility of formation of shrinkage cavities. In this case the limiting inlet velocity, which depends also on the runner system geometry can be equal up to 2,5 m/s [2].
In high pressure die technology the inlet velocity of metal need significantly higher value to avoid the main technological problems which are difficulties with the complete removal of a gas phase from a mould cavity, under conditions of a total lack of permeability of the metal mould and a very short time (a fraction of a second) of its filling. Under such conditions, the subsurface gaseous porosity of a metallurgical origin – related to the emission of gases dissolved in a solidifying alloy – can superimpose itself over the occlusion phenomenon in the shot sleeve. This significant defect of die castings can be partially restricted by improvements of mechanisms and parameters of machines. The following procedures are applied: die casting in

vacuum, application of multiphase or phase-less injection systems enabling high pressure moulding (e.g. up to 900 MPa), shortening the time of pressure build-up in the IIIrd or IVth phase of the final pressure moulding of alloy (approximately 10 µs) as well as passing into the category of low-pressure die casting systems

Due to difficulties related to safety of the visualization the filling process of the casting mould with liquid metal in the real time, the influence of the selected parameters is often being determined on the grounds of a computer software based on hydrodynamic calculations [8÷10].

Methods of visualisation of filling mould cavities with metal can constitute a useful tool for the estimation of the influence of individual parameters on the flowing process as well as for the verification of the obtained experimental results with the computer simulation results.

Therefore the aim of our own research [12] and others [11] was the estimation of the influence of the runner system geometry and inlet velocity of aluminium alloy in a thixoforming state or model liquids of the determined viscosity characteristics on phenomena occurring during filling the mould. The development of the visualization method of the process was an additional purpose of our investigations. The comparison of the experimental results with the ones calculated with the Novacast (Novaflow&Solid) calculation module for the selected various casting conditions is also presented in the paper.

2. Stand for model investigations

Essential elements of the stand for model investigations of the 2nd phase of the pressure die casting are illustrated in Fig. 1. The detailed description of the stand is given in papers [10, 12]. Its main element is the horizontally situated model of the squeeze chamber, made in 1:1 scale, together with the plunger and the model of casting mould. The squeeze chamber model is made from a colourless extruded pipe of PMMA of an internal diameter equal 70 mm and the chamber length of 500 mm. The mould of a rectangular cross-section and dimensions 280 mm (height) x 190 mm (width) and of an adjustable thickness, which can be equal 25, 15, 10 and 5 mm (by application of inserts) - was used in experiments. Two inlet systems of a rectangular cross-section were applied, which could be placed in the middle of the bottom wall of the mould or from its left or right side, had the same width of 48 mm but different thickness of 3 or 4,7 mm.

The stand enables an easy installation of the needed sensors and measuring converters. Modern pressure converters type MBS-32 of the Danfoss Company, were used for measuring pressure in the squeeze chamber and in the mould. Magnetostrictive linear converter, type BTL2 of the Balluf Company, was used for measuring the plunger shifting, which acceleration is measured by means of the acceleration converter, made from integrated elements type ADXL50 of the Analogue Devices Company. Phenomena occurring in the model mould – during its filling – are recorded, at the proper lighting, by the video camera and then processed by computer.

The main part of research was performed on three testing moulds with rectangular cavity shape and the following dimensions: 280 mm (height) x 190 mm (width) x 10 mm (depth).

The 3 inside parts of die moulds were used in research: without any elements inside, with 2 circular or 2 semi-rings elements.

All 3 models versions had air vents located on their upper surface. The following markings and venting modes were used in the tests:

– O-O-O – full venting - total surface of venting holes 52 mm^2,
– Z-O-Z – reduced venting – total surface of venting holes 8 mm^2,

The presented below experiments were performed for two model liquids, namely:

– model liquid of a kinematic viscosity of 1.39 mm^2/s) (1.39 cSt) - marked „LIQUID 7%", which corresponds approximately to the aluminium alloy viscosity at die casting,
– model liquid of a viscosity of 9.46 mm^2/s (9.46 cSt) - marked „LIQUID 80%", which can represent the viscosity of other aluminium alloys in the state of a semi solid casting.

Fig. 1. View of the stand for analysis of the flow phenomena occurring during research of filling the model mould [12]

3. Investigations performed at the test stand

The research program presented in the hereby paper was as follows:

1. Determination of the influence of the plunger piston velocity on the volumetric rate of filling of the model liquid – achieved by means of filming the process;
2. Pressure measurements in the shot sleeve and in the model casting mould;
3. Numerical simulation of the process of filling the cavity of the model casting mould at plunger velocity of 0,3 m/s) with the application of the Novaflow software;

Comparison of results obtained from simulation calculations with the results of experiments at the test stand.

Analysis of the process of filling the model moulds with the model liquid

The data in Table 1 presented results handled statistically by means of the Excel program provide empirical dependencies, which can constitute the basis for forecasting the average actual rate of filling of the model liquid of a determined viscosity (being inside the tested variability range) under the known conditions of the mould filling (two kinds of model liquids in the gate hole of model moulds (gate 4,7 x 48 mm) with 2 venting mode).

Table 1.
The list of empiric formulas for the determination of the actual volumetric rate of model liquid during filling model moulds. Experiment concerns 2 different model liquids, 2 venting modes and 2 sizes of filling gates

Actual average volumetric rate of filling determined by filming Q_{film} [cm³/s].	
Average volumetric rate of filling by model liquid „LIQUID 80%”	
Venting mode O-O-O; Filling gate 4,7 x 48 mm	Q_{act} = - 23.732 v^2_{total} + 239.12 v_{total}; R^2 = 0.99
Venting mode O-O-O; 3,0 x 48 mm	Q_{act} = - 12.748 v^2_{total}+ 163.24 v_{total}; R^2 = 0.99
Venting mode Z-O-Z; Filling 4,7 x 48 mm	Q_{act} = - 23.121 v^2_{total} + 221.7 v_{total}; R^2 = 0.99
Venting mode Z-O-Z; Filling 3,0 x 48 mm	Q_{act} = - 10.112 v^2_{total} + 131.7 v_{total}; R^2 = 0.98
Average volumetric range of filling by model liquid „LIQUID 7%”	
Venting mode O-O-O; Filling 4,7 x 48 mm	Q_{act} = - 18.48 v^2_{total} + 181.21 v_{total}; R^2 = 0.99
Venting mode O-O-O; Filling 3,0 x 48 mm	Q_{act} = -12.697v^2_{total} + 153,83 v_{total}; R^2 = 0.99
Venting mode Z-O-Z; 4,7 x 48 mm	Q_{act} = - 20.198 v^2_{total} + 178.99 v_{total}; R^2 = 0,98
Venting mode Z-O-Z; Filling 3,0 x 48 mm	Q_{act} = - 9.15 v^2_{total} + 117.27 v_{total}; R^2 = 0.99

Pressure measurements were used for determining the pressure changes in the shot sleeve and in the mould depending on the conditions of the process realization. Pressure curves were analysed in correlation with characteristic phases of the shot piston displacement. The time of filling the mould cavity with model liquid as well as the volumetric rate of filling were determined on this basis. The following data were determined maximum pressure in the shot sleeve ($p_{pr.\ max}$.) and in the die mould ($p_{f.\ max}$.) (Fig. 2 and 3).

Analysis of graphs confirms the expected correctness concerning the pressure distribution in the shot sleeve and in the mould, which is related to resistance of a liquid flow via the gate hole and vents. At the theoretically constant venting surface (O-O-O venting mode) the maximum pressure changes exponentially with the increase of the liquid velocity in the gate hole. Higher pressure values both in the shot sleeve and in the mould are obtained for gate holes of a smaller surface area and for higher viscosity of model liquids.

Examples of filling the model moulds recorded by filming are given in Figure 4. Analysis of successive pictures indicates that entering of liquid into the mould cavity is usually accompanied with swirling, which ceases after some time as the results of forcing through the venting holes a part of the liquid. This delay in obtaining compactness by the liquid stream, which occurs at the nominal density, is the reason that the actual volumetric rate of filling is lower than the one calculated from the rate of filling the mould cavity.

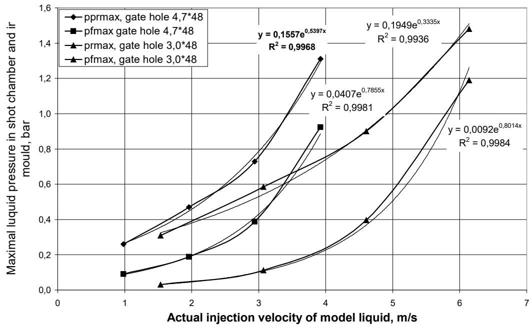


Fig. 2. The dependence of the maximum pressure in the shot sleeve (ppr. max.) and in the mould (pf. max.) on the liquid velocity in the gate hole. „LIQUID 80%, for a hole: 4.7 x 48 mm”, O-O-O venting mode

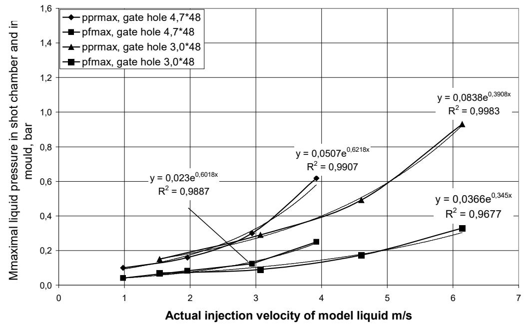


Fig. 3. The dependence of the maximum pressure in the shot sleeve (ppr. max.) and in the mould (pf. max.) on the liquid velocity in the gate hole. „LIQUID 7%, for a hole: 4.7 x 48 mm”, O-O-O venting mode

4. Results and analysis of the selected simulation results of the process of the model moulds filling

The selected simulation results of the filling the technological cavity of model moulds, versions as on Fig. 4 presented above as examples. It should be mentioned, that values of the filling degree and time of casting – placed in the legend of individual pictures - are cumulative values related to the simulation results, in which the filling of the shot sleeve (squeeze chamber) as well as the model mould and the total time of piston movement were taken into account. An analysis of flow phenomena in the 2nd phase of the die casting process requires data, which are directly related to the filling process in manner formulated in table 1 for all tested moulds.

In the numerically simulated phenomena –in the case of filling the moulds containing circular inserts (version II) and inserts of half-rings shape (version III) a highly regular form of a free liquid surface in the mould cavity is seen - even at higher velocities of the process. However, in reality, such forms are very difficult to achieve even at the velocity in the inlet gate being 1-2 m/s.

The unquestionable advantage of the process is the easiness of preparation of the output data for calculations, its elasticity and the possibility of fast introduction of changes and estimation the effects of those changes.

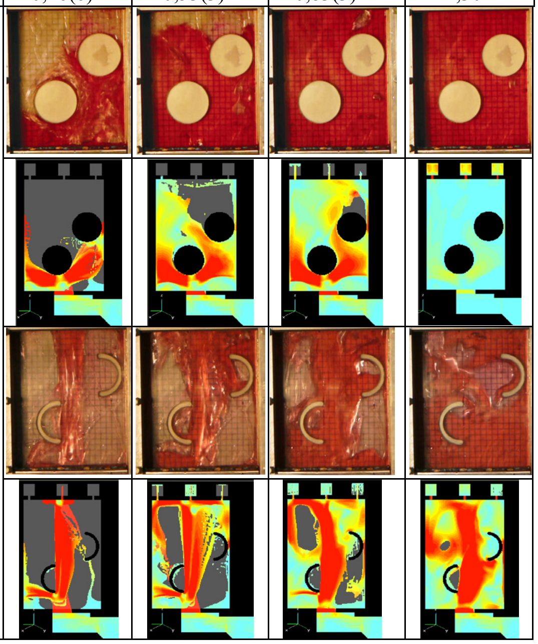
Plunger velocity v_p Ingate velocity v_{gate} Reynolds number	DATA: Model mould: 280 x 190 x 10 mm with inserts, filling gate 4,7 x 48 mm; ingate surface: 225,6 mm^2, air venting mode: O -O-O, F_{vent} = 52,00 mm^2. Model liquid"LIQUID 80%, viscosity υ_l = 9,46 mm^2/s; density ρ_l = 1,12 g/cm^3,			
	Filling time 0,26(6) s	Filling time 0,53(3) s	Filling time 0,83(3) s	Filling time 1,30 s
v_p=0,3 m/s v_{wl}=5,88 m/s Re 4920				

Fig. 4. Successive phases of model moulds filling in dependence of the kind of mould (versions II and III), the way of model liquid supply (central gate, right gate) and the time of the filling process – recorded by filming and compared with the results of simulation performed by numerical calculation (Novaflow&Solid) for the various testing conditions

5. Summary

The presented hereby considerations indicate that such parameters as the geometry of the gate system and the injection velocity influence the model liquid character, which corresponds to the quality of the obtained die castings.

The following conclusions can be drawn on the basis of the photographed - in an actual time – the flow phenomena and on the measurements of the rate of filling:

1. Dimensions and geometry of the gate system of the mould as well as the liquid velocity have a decisive bearing on the character of the liquid flow during the mould filling. At the constant filling velocity the characteristic of flow depends more on the depth of the gate system than on its width, thus, the critical filling velocity is inversely proportional to the gate hole depth.
2. At an asymmetric placement of inserts inside the mould cavity the axial introduction of the model liquid does not provide conditions of mould filling, which would eliminate air voids, and in consequence the time necessary for the total stabilisation of model liquid movement is prolonged.
3. The results obtained from experimental tests confirm the ones calculated on the basis of the Reynolds number. At the presently applied technology of die casting, where gate systems are of a depth up to 10 mm, the gate velocity of the range 0.3÷0.5 m/s is considered the proper one for maintaining the flow of the assumed character. In the case, when the pressing process is performed in the state of partial crystallisation the gate velocity can be one order higher without changing the flow from laminar to the intermediate one.

The stationary flow processes of the model liquid in a mould - of any shape of the cavity -are more easily obtainable when the liquid used is of a higher viscosity, while the velocity of removal of gaseous bubbles occluded by liquid is higher for liquids of a low viscosity.

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