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Numerical analysis of stresses in mould in the process of pressure casting

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Abstract. Optimization of design and technology of pressure casting mould is a complicated problem due to the complex character of the wear mechanism including such processes as: thermal fatigue, mechanical fatigue, erosion and cavitation, dissolving of mould material by liquid metal, adhesion of cast to mould etc. This paper presents ways of assisting a pressure casting process with the usage of numerical methods. Computer simulation has been conducted which enables an analysis of the behavior of molten alloy inside the casting mould and stresses in mould. A computational model of this process has been created with the help of ANSYS-CFX, a program which uses advanced computational methods including CFD.
Keywords: numerical analysis, pressure casting die, liquid aluminum

1. Introduction

Optimization of design and technology of pressure mould is a complicated problem due to the complex character of the wear mechanism which includes (among others) such processes as thermal fatigue, mechanical fatigue, erosion and cavitation, dissolving of mould material by liquid metal and adhesion of cast to mould. The mould's durability depends mainly on the choice of material for the mould and its surface layer where the propagation of fracturing and cracking must be delayed as long as possible [4, 5]. The reason why premature damage of pressure moulds occurs is connected with uncontrolled superposition of internal stresses resulting from the process of surface layer manufacturing and stresses cyclically generated by external forces during the casting process. Therefore, in order to extend the durability of the mould it is crucial to know the stress distribution caused by external factors generated in the mould during the whole cycle of the casting process [6, 7].

Nowadays, the whole process of designing is done in virtual reality and is assisted by suitable programs from the initial stages of designing a machine to structural and technological analysis of each of its parts. Thanks to these programs it is possible not only to obtain a true picture (realistic visualization) of the designed structure but also to investigate interrelation between all cooperating parts and evaluate their interdependence when the mould is being used [1, 2, 3]. In addition, a simulation of the mould's operation may be run and collision analysis may be performed (e.g. incorrect angles can make it impossible to remove the cast from the mould cavity). Unlike the more complicated formulae and stress interpolation hypotheses, simulation allows for analysis of durability of the mould. That is the result of the fact that boundary conditions, which vary over time, can be included in the computation. This in turn allows for analysis of stress pattern in any part at any given time during the operation cycle of the mould. Therefore, it is possible to optimize the design and technology of manufacturing of the mould e.g. by choosing most appropriate heat treatment and finishing.

2. Numerical model definition

Dynamic model of stress in pressure casting mould was performed on a specimen whose shape was a simplified version of a real casting manufactured by WIFAMA-PREXER Company. Because modeling of the phenomena occurring during pressure casting is highly complex, a simplified 2D model (Fig. 1) obtained as a cross section of the mould (Fig. 2) was used in numerical computation.

The input data of the simulation of filling process included the following real conditions at the measuring position in WIFAMA-PREXER Company:

- liquid casting alloy — AlSi9Cu3 (according to DIN),
- temperature of the liquid alloy — 650°C,
- mould material — hot work tool steel 1.2343 (X37CrMoV5-1) after heat treatment in order to obtain hardness of 44-46 HRC,
- experimentally determined plunger pressure characteristics measured during real casting process [11].

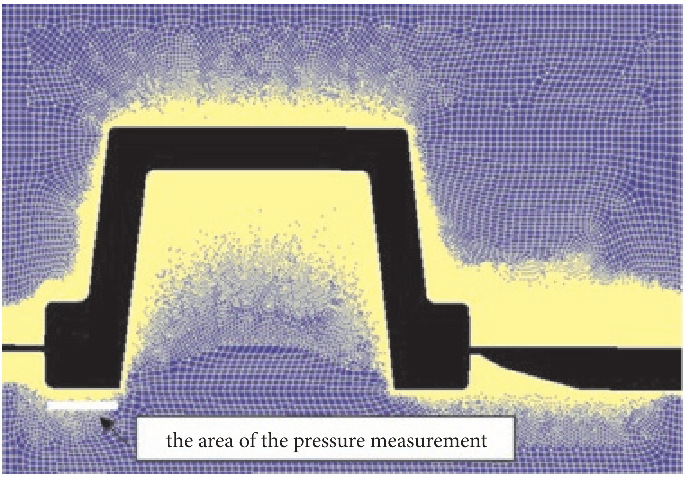

Fig. 1. Discreet model 3D of the pressure casting die

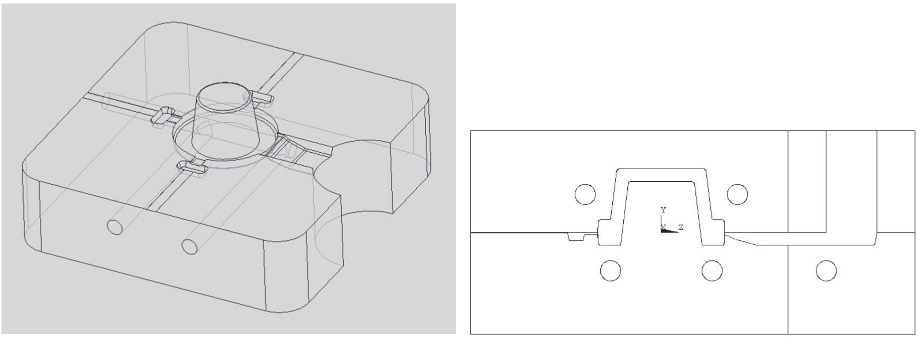

Fig. 2. Model and cross-section of the pressure casting die

Computer simulations of processes referring to heat exchange and flow which change over time were performed. The heat properties of the mould and flow characteristic of the liquid aluminum alloy were considered [8, 9, 10]. In order to analyze the flow phenomenon, a two phase flow (air-liquid) model was used.

Simultaneously, a solution was found for problems connected with temperature distribution in the mould. These were the effects of impact of the hot alloy on mould surface. As these phenomena change quickly over time, it is necessary to analyze very small time steps of as little as a few microseconds. Such small time step must be selected to obtain a measurement of required accuracy. Computer calculations covered the whole process until the moment the mould cavity was completely filled with the liquid alloy (the time of filling $t_w = 10$ ms [11]).

At the first stage it was assumed that the gradient of temperature of mould and liquid alloy is about 500°C. This state was considered to represent the situation during several of the first injections of the liquid alloy into the mould cavity which was confirmed by experimental research using specially equipped casting machine. At the next stage, the temperature distribution was omitted, since the temperature gradient between the mould and liquid aluminum was insignificant. This situation occurs after the first few injections.

3. Results of simulation

The computer simulation of the process of pressure casting showed the distribution of temperature and pressure on the surface of the mould cavity [12]. As a result it was possible at the next stage of simulation to determine, continuously at given time steps, the distribution of real stresses occurring on the surface of the shaping element and inside it (Fig. 3). An analysis of stresses along specified paths was also conducted (Fig. 4).

For superposition of stresses, the time step of 0.8 [ms] was chosen from all the analyzed time steps. Next, this time step was used for calculation of stresses after thousands of operations of filling the mould cavity with liquid aluminum alloy. This allowed for comparison between superposition of stresses during one of the first injections and superposition of stresses after several thousands of injections. Longitudinal stress distributions along selected paths (Fig. 4) for each of the cases in question are presented in figures 5 and 6.

As it can be seen in figure 5, in the case of the first injections when the thermal gradient in surface layer is considerably large compression, stress reaches the maximum value of –225 MPa. Compression changes into tension at the distance of 0.2 mm reach the maximum value of +100 MPa at the distance of 0.25 mm and then it asymptotically approaches zero. After the temperature of the surface layer stabilizes (it occurs after less than a hundred injections), the distribution of stresses changes slightly (Fig. 6), but there is still compression which reaches values from –210 MPa to –120 MPa. This distribution of stresses is very advantageous as far as initiation of fatigue cracking is concerned, as they mostly appear in the areas where tension occurs.

There is a difference in longitudinal stresses along a surface on which the stream of liquid aluminum flows along the path S5 in figure 4 (cf. Fig. 7). In this case, tension in the surface layer reaches +450 MPa (after the temperature of the mould has stabilized). Tension occurring on the surface is the effect of direct activity of stream of molten aluminum alloy on the mould casting material in the area of injection. The stress gradient, which occurs between the states before and after temperature stabilizes, reaches the value of about 750 MPa. It has undesirable effect on fatigue strength, which may in turn cause micro-cracking due to fatigue. Therefore, it is advisable to use technology which will create compression in the surface layer to eliminate the tension in this layer generated while the mould is being used.

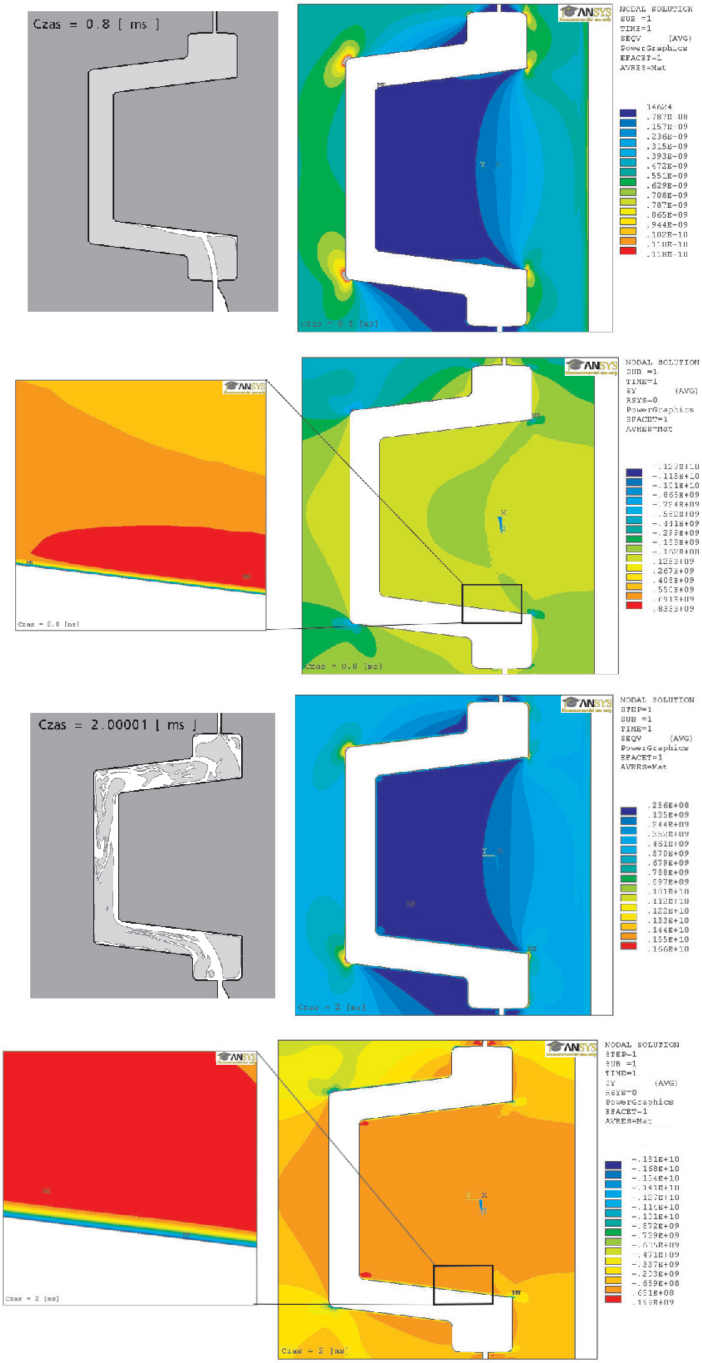

Fig. 3. Reduced and longitudinal stresses inside the pressure casting die for selected time steps

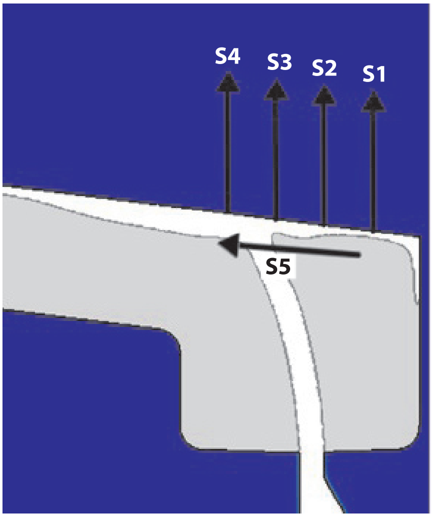

Fig. 4. Chosen area and paths along which the superposition of the stresses from external loads has been calculated

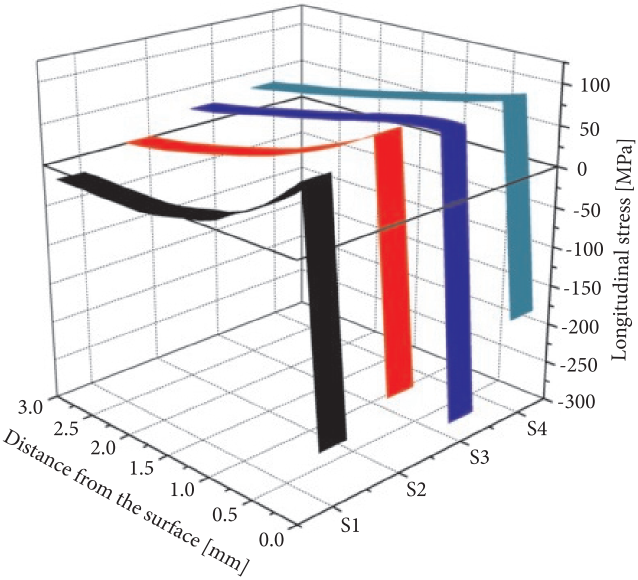

Fig. 5. Stress distribution taking into account distribution of currant pressures inside the pressure casting die for selected time steps — before achieving a steady state temperature

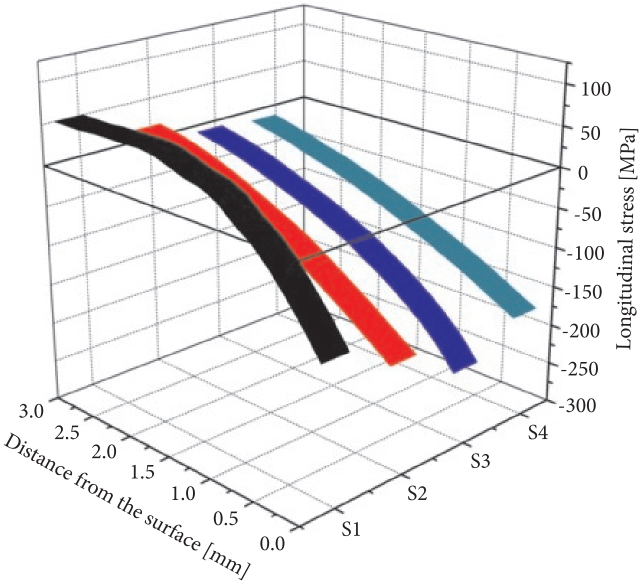

Fig. 6. Stress distribution taking into account distribution of currant pressures inside the pressure casting die for selected time steps — after achieving a steady state temperature

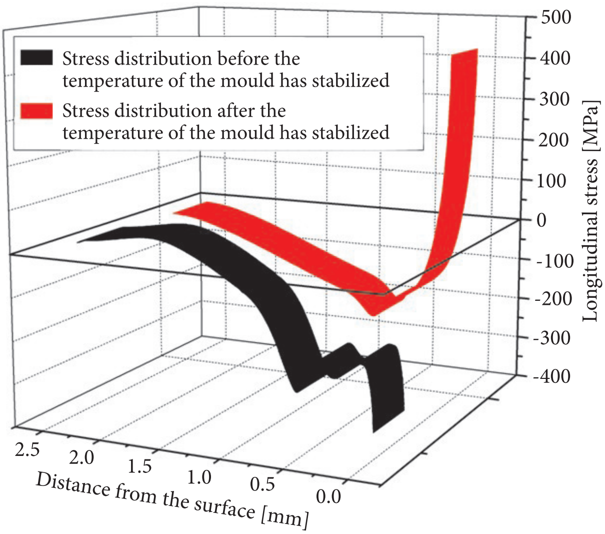

Fig. 7. Longitudinal stress distribution inside the pressure casting die for selected time steps — along path S5 presented in fig. 4

4. Conclusions

Computer simulation is an effective way of analysis of the phenomena which occur during the complex pressure casting processes. Correctly identified design specifications enable using optimum parameters of filling, which produces good castings and improves durability of the mould. Thanks to the performed simulation, design choices may be evaluated and errors may be eliminated already at the stage of designing. The great advantage is shorter time needed to implement the design. If errors in design specifications are observed only when the mould is used in the real casting process, correcting them requires additional changes and these can be very costly and time consuming.

Thanks to the performed simulation of filling, we can introduce changes to eliminate such negative phenomena as erosion or cavitation or at least to limit their scope. Changes in this area may be connected with the position of the gate, its geometry and the change of the shape of mould surface. However, in case such changes cannot be introduced, simulation results may suggest technological methods of surface layer refinement to eliminate unwanted erosion and cavitation. The layer must be chemically resistant to aluminum and its alloys and must be hard enough to ensure durability and wear resistance.

Stress distribution that has been obtained may be used as a criterion for choosing technological surface layer. It is considered an important parameter for further industrial implementation, as it enables superposition of stress in surface layers of mould elements.

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Numeryczna analiza naprężeń w formie podczas procesu odlewania ciśnieniowego

Streszczenie. Optymalizacja konstrukcji i technologii formy ciśnieniowej to skomplikowany problem z uwagi na złożony charakter mechanizmów zużycia eksploatacyjnego, które obejmuje takie procesy jak: zmęczenie cieplne, zmęczenie mechaniczne, erozja i kawitacja, roztwarzanie składników materiału formy przez ciekły metal, adhezyjne przywieranie odlewu do formy itd. W niniejszej pracy przedstawiono wspomaganie procesu odlewania ciśnieniowego przy użyciu metod numerycznych. Przeprowadzona symulacja komputerowa pozwala na analizę zachowania się strugi ciekłego stopu metalu wewnątrz formy odlewniczej i naprężeń w formie. Do przeprowadzenia modelowania komputerowego tych zjawisk został użyty program ANSYS-CFX, który wykorzystuje zaawansowane techniki obliczeniowe m.in. z dziedziny CFD.

Słowa kluczowe: analiza numeryczna, forma ciśnieniowa, ciekłe aluminium