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# Gating Systems for Sizeable Castings from Al Alloys Cast into Ceramic Moulds

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## Abstract

In contrast to casting to conventional non-reusable "sand" moulds, for which calculating technique for an optimum design of the gating system is comparatively well-developed, a trial-and-error method is applied mostly for casting to ceramic shell moulds made by the investment casting technology. A technologist selects from gating systems of several types (that are standardized by the foundry mostly) on the basis of experience. However, this approach is not sustainable with ever growing demands on quality of castings and also the economy of their fabrication as well as with new types of complex sizeable castings introduced to the production gradually (by new customers from the aircraft industry above all) any more. The simulation software may be used as a possible tool for making the process of optimising gating systems more effective.

**Keywords:** Application of Information Technologies in the Foundry Industry, Solidification, Gating Systems, Ceramic Moulds, Simulation

## 1. Introduction

The investment casting technology is a progressive technology that facilitates a production of very complex thin-walled castings of dimensional and shape stability. At the same time, this technology belongs to a group of technologies working with non-reusable sand moulds, which show considerable differences as compared with common technologies of this category. They express themselves also at designing shapes and dimensions of gating systems. The material of a ceramic mould has different properties in comparison with the conventional sand mould both from the viewpoint of heat transfer after metal casting and from the viewpoint of technological properties of the shell, like its strength and permeability. Moreover, the metal is cast to "hot" moulds above all, i.e. shortly after they are withdrawn from the annealing furnace, whereas it is cast "in cold state" to conventional sand mould. Moreover, the flow velocity of the molten metal to shell moulds is higher as compared to casting to sand moulds, which is caused by lower resistances and a lower friction owing to the smooth and hard surface of the shell above all. The thickness and the material of the shell are other factors influencing the optimum casting of a shell mould, which influence the heat transfer and accumulation from the viewpoint of the temperature field after casting above all. It is influenced also by the general construction of the cluster and the selected temperature of the shell preheating. An example of the gating system solution of a specific thin-walled sizeable casting from the viewpoint of optimising the metal flow in the cavity of the shell mould above all is given in this article. This optimisation is very important because the air may be enclosed at filling the shell by metal in consequence of an unsuitable construction of the gating system (of the shape and position of gates) and may cause thus the origin of defects such as shrinkage porosities, blow-holes, and porosities [1, 2].

## 2. Main principles of assembling gating systems for precision casting

The construction and the shape influence the origin of defects of porosities and shrinkage porosities types in the main. It is necessary to meet following principles at assembling the gating systems:

- To provide a sufficient velocity and direction of metal flow to all parts of the mould before it solidifies.
- To ensure as steady as possible metal flow without turbulences (in order to limit the oxidation).
- Small and middle-sized castings should be arranged so that they solidify evenly. A circular arrangement is to be selected rather than line arrangements because thermal conditions of castings at the end of branches differ from thermal conditions in the centre in case of a line arrangement, see Fig. 1.

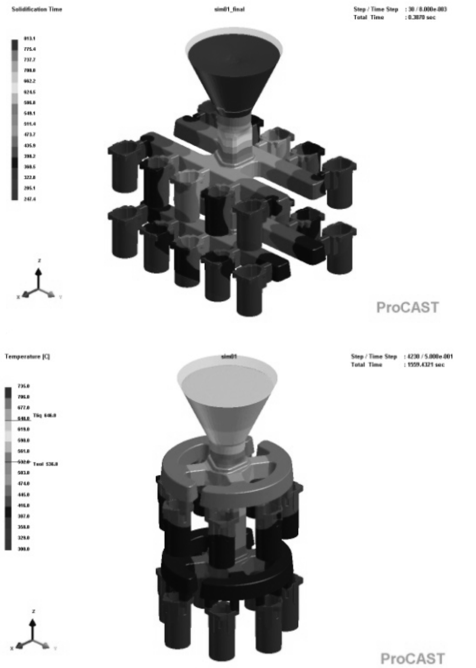


Fig. 1. Comparison of temperature fields for circular and line arrangement of a gating system

- Sprues and risers should be positioned so as to facilitate an easy separation of the casting from the gating system.
- The connection of castings to the cluster must satisfy requirements on coating and drying of the shell.
- Sprues must not be positioned in places of thin walls or vertically to brittle cores, where the metal flow could cause their destruction.

The cross-section of the metal flow narrows down at a free run of the metal to the sprue hole. A large narrowing of the metal flow occurs in long sprue holes so that air is sucked in through permeable walls of the shell. The permeability of shell influences thus the quantity of the sucked in air. To lessen the amount of air sucked in, the sprue hole should narrow downwards to ensure a constant volume rate of metal flow (to increase the linear metal velocity).

There are several types of gating systems for precision casting. A top filled gating system is used as a standard. This system is used both in foundries of steel and of aluminium alloys most commonly. It is suitable for undemanding castings above all at casting aluminium alloys. A turbulent flow of metal occurring at the height of the sprue hole exceeding 300 mm and a difficult positioning of filters are its disadvantages. The metal use efficiency tends to be up to 50% at this type of casting. The second possible position of the sprue is the so-called “cage gating system”, see Fig. 2. This type is used for large and quality demanding castings mainly. Positioning filters in the lowest point of the cage and thus an ideal bottom up filling of the gating system by the metal are its advantages. A longer assembling of the gating system and low metal use efficiency up to 30% are its disadvantages.

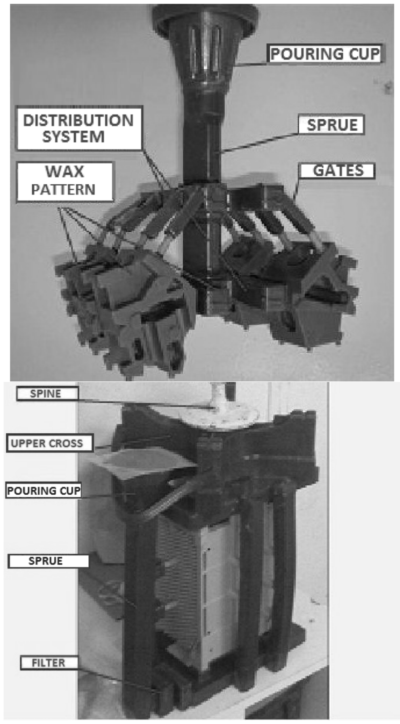


Fig. 2. Sprue positions: top filling above, cage gating system below

The solidification of metal in the mould of sizeable castings in the main is accompanied by a change – by a reduction of metal volume that causes shrinkage porosities and shrinkage cavities in the casting. A compensation of change of metal volume at the solidification should be achieved by a controlled, gradual solidification of a casting. It is impossible to avoid thermal knots and differences of wall thickness at complex castings usually. A directional solidification can be achieved by many different measures. These measures include e.g. an elimination of thermal knots by the help of risers, a controlled cooling and heating of certain mould parts using chills and insulations. It is possible to use e.g. the compressed air to intensify cooling of certain mould parts. In spite of local differences of cooling speed, the geometry of the casting plays the main role in determining the total solidification time. There are several rules for the calculation of the time of solidification of a casting, the most famous and the oldest of which is the Chvorinov's Rule stating that the total time of solidification of castings is a direct function of the ratio of their volumes to their areas, see (1). The k coefficient differs according to different authors, e.g. according to Dietert k= 1.8 – 2.5 depending on the wall thickness of the casting. [3]

$$T = k*(V/A)^2 \text{ [s]} \tag{1}$$

The basic rule says the time of solidification of a casting should be lower than the time of solidification of a riser (2).

$$T_{riser} > T_{casting} \tag{2}$$

The contemporary high-power simulation software, e.g. ProCast, may help in solving and predicating the origin of defects associated with the unsuitable construction of the gating system and the solidification of a casting.

## 2.1. Simulation of a sizeable casting

A specific sizeable casting (of 700 mm length) was selected for the study jointly with FIMES a.s. foundry. Numerical simulations of its filling were done in ProCast program in cooperation with MECAS Esi Brno company subsequently.
Surface and volume networks of the casting and of the gating system were made on the basis of 3D construction in CAD Unigraphics NX in the STL format. A simulation of the filling course was carried out subsequently, the result of which are shown in Fig. 3.

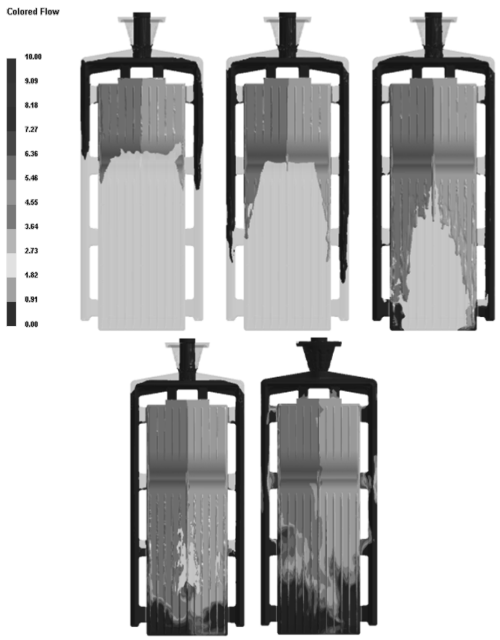


Fig. 3. Course of filling

It is evident from Fig. 3 that the metal was filled by the upper two and the lowest two gates at the beginning and that metal whirled a lot. The gating system was shortened for further simulation, see V2.
Optimised mould versions marked V1, V2, V3, and V4 were made on the basis of the first simulation, see Fig. 4.

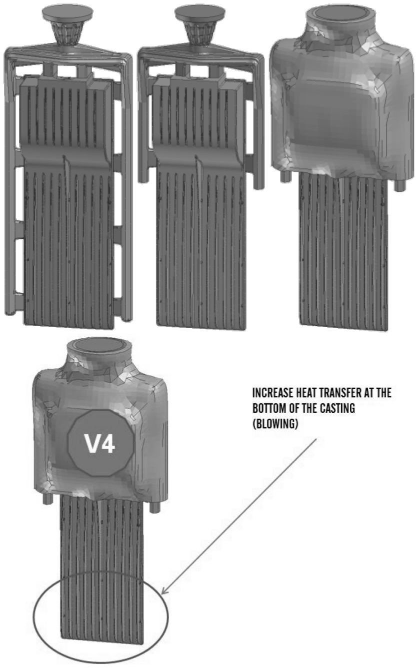


Fig. 4. Optimized V1, V2, V3, and V4 versions

The upper part of the casting of the V3 version was insulated by sibral to increase the temperature gradient and to achieve a directional solidification. To achieve even a higher effect and a higher temperature gradient, a cooling was added in the V4 version to the bottom part of the casting by blowing in compressed air. Fig. 5 shows the result of comparing temperature fields after filling V1 and V2 versions.


Fig. 5. Temperature fields of V1 and V2

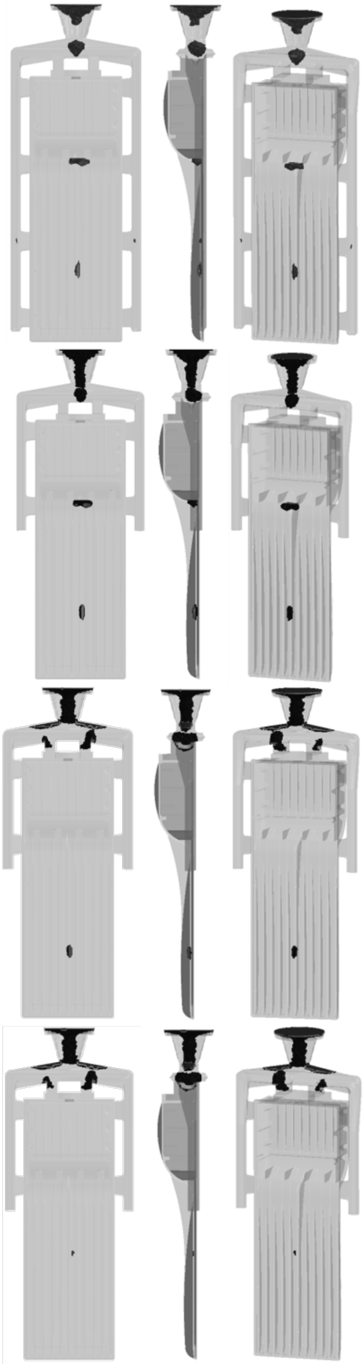

Fig. 6. Distribution of micro porosities of V1 to V4

## 3. Conclusion

Simulations made have shown that air gets enclosed in certain places of the casting at the solidification, in the area of ribs in the main so that there is a risk of porosities creation. Moreover, the simulations of temperature fields have shown an uneven solidification of some areas and a consequent risk of micro-shrinkage porosities creation. The optimisation made at V3 and V4 above all have shown possibilities how to achieve a better quality of castings in practice by means of a directional solidification and other simple measures like using an insulation material and also a controlled cooling by blowing in compressed air. The technology of casting the V4 version came out as the best out of the simulations applied. The occurrence of porosities was minimised there, which was confirmed subsequently by X-ray tests of castings made by this technology. The simulation by the help of ProCast software has proved successful in this case and its results were certified by material castings.

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