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Prediction and validation of shape distortions in the simulation of high pressure die casting

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ABSTRACT

The use of the thermomechanical simulation is very infrequent in the metal casting industry although the associated results are really useful for the manufacturing process. The main reasons are the complexity, the long calculation times and the difficulties to interpret the results.

The parts manufactured by metal casting processes cool from its filling temperature to ambient, which causes a certain stress-strain state. Although the stress levels might be significant, the main worry of the foundrymen is usually the shape distortion. That is, the mismatches between the desired dimensions and the real ones. The problem is that the results obtained from numerical simulation are not directly useful to cover this industrial necessity.

This work presents the prediction obtained using the thermomechanical simulation for the final dimensions of a component manufactured in aluminium alloy by high pressure die casting (HPDC) and its validation with the final dimensions of the manufactured component. The methodology established to forecast the mismatches with the reference geometry is also detailed, as it may be useful to encourage the use of this type of simulation in the metal casting industry.

1. Introduction

The numerical simulation is a technology quite extended at the metal casting industry, although the typical use is restricted to the thermal-flow problem. That is, the coupled analysis of the laws of fluid dynamics which governs the cavity filling, see reference [1], combined with the heat transfer analysis that directs the solidification and the cooling process, see reference [2].

The inclusion of the thermomechanical analysis in the numerical simulation is very infrequent in the metal casting industry, although the associated results are really useful for the manufacturing process. The main reasons are the drastic increment in calculation times, the complexity of the correct set-up of the simulation and the difficulty of the results interpretation.

The components manufactured by the different metal casting processes experience a cooling process from its filling temperature to ambient temperature. This cooling causes the component contraction. This contraction does not occur uniformly along the whole component due to the existent thermal gradient in it, the mould presence, etc. causing a certain distribution of stresses and strains along the component, see references [3,4]. Although these stress levels might be significant and may cause problems as hot tearing, see reference [5], one of the main worry of the foundrymen is usually the shape distortion. That is, the differences between the desired dimensions and the real ones of the manufactured part. In cases where the differences are notable, it may cause the rejection of the component.

The mould is also subjected to thermal gradients and as consequence to thermal stresses and strains. The moulds manufactured in relatively weak materials usually suffers cracks and breaks during the cooling process of the part, as it is the case of the sand casting and the investment casting. In cases where the mould material is strong, as for example in high pressure die casting (HPDC), some strains and displacements may happen but they are less significant than those that take place in the component. The main reason is the combination of higher strength and lower thermal gradients compared with the component.

To obtain trustworthy simulations of the metal casting processes is not a trivial task. The origin of the thermal stresses and strains is the thermal history suffered by the component and/or the mould. So, in order to achieve a reliable prediction of the thermomechanical behaviour is essential to obtain an accurate thermal prediction. The use of the appropriate values for the model parameters is required. These

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parameters, when the analysis is limited to the thermal behaviour, are the material properties, the heat transfer coefficients and the boundary conditions. The determination of these values is always difficult, especially in cases as the HPDC, where the high process temperatures are combined with fast fillings and the continuous manufacturing process based on consecutive cycles. These difficulties are increased when the thermomechanical analysis is included in the simulation. In this case, it is also needed assign the appropriate material model, the correct mechanical boundary conditions and of course the suitable material properties relative to the mechanical behaviour.

Nevertheless, the difficulty does not end with the obtaining of an accurate thermomechanical simulation. The results analysis is another aspect that must be considered. The results obtained from numerical simulation are traditionally the corresponding to the stresses, strains and displacements. But these results do not cover directly the necessity of the foundrymen of predicting the mismatches with the reference geometry.

In order to facilitate the application of the thermomechanical simulation in the metal casting industry, it is interesting to study alternatives to avoid some of these difficulties. In the work presented hereafter. The validation of the thermomechanical simulation to predict the final shape of a component manufactured by HPDC has been tackled together with the development of a methodology that makes results interpretation easier according to the foundrymen necessities.

2. Methodology

2.1. Thermal simulation

Thermal stresses are caused by the thermal gradient suffered by the parts, so the accurate thermal simulation is essential to achieve a reliable thermomechanical simulation.

The reliable thermal simulation of the HPDC process is a tricky problem. The moulds are usually complex, formed by fixed and movable plates, cores, tempering channels, cooling channels, etc. The manufacturing process is continuous, based on consecutive cycles, which must be taken into account in the simulation due to they are very related with the thermal stabilization of the mould. At the beginning of the HPDC process the mould is usually too cold, this causes the alloy freezing during the injection preventing the cavity filling. The successive cycles go heating the mould but while it is not heat enough the part quality will not be assured. Porosity or surface defects may happen. Notice that mould thermal stabilization does not mean uniform or constant temperature, a thermal gradient exists along the mould which also varies during the cycle phases. Moreover, different machine parameters must be taken into account as the furnace temperature, the pouring process into the container, the piston velocities, etc. The alloy fills the cavity at very high velocities and is subjected to very fast cooling rates. The part geometries usually are complex with very thin sections. All of these difficulties make patent the challenge associated with this type of numerical simulation.

Obviously, the appropriate assignment of all these values is a requirement to obtain reliable results. Some of them are easily obtained as the cycle times or the furnace temperature but others as the materials properties or the heat transfer coefficients are much difficult to obtain experimentally. The traditional solution for these unknown values is to employ bibliography data but their availability is limited and moreover they usually correspond to standard average values. One alternative that makes possible to adjust the simulation models avoiding these difficulties is the use of inverse methods.

The application of inverse methods to metal casting simulation consist of an iterative procedure that modifies several model parameters until reaching results close enough to the reference measurements. In metal casting processes, the reference measurements correspond to the temperature evolution measured at several controlled points of the mould and/or the cast part. The model parameters subjected to modification are usually those whose value assigned is more uncertain. Inverse methods have been successfully applied to metal casting modelling by different authors, see references [6–11]. This is the methodology which has been followed in this case to adjust the thermal simulation model of the HPDC process. The numerical simulation software used, called ProCAST, is based on the finite element method and is specially focused on metal casting simulation.

2.1.1. Thermal model adjustment

The procedure followed in this case to adjust the model has been made public in reference [12]. For this reason, only a general vision of this process is described here to explain the basis of the adjustment performed. The interested reader may consult the mentioned reference for a more in deep explanation of the adjustment procedure followed.

The model fitting has included the adjustment of the material properties and the boundary conditions, including the heat transfer coefficients. The iterative nature of the adjustment methodology makes very advisable to base the adjustment in simple cases to reduce calculation times. For this reason, the adjustment has been performed in two different phases: the first one is based on one gravity prototype and the second phase is based on one HPDC prototype. The iterative process of adjustment has been executed mostly by means of manual procedures.

The gravity prototype corresponds to a simple cylindrical geometry (part ∅40 mm 200 mm length and 30 mm mould wall), see Fig. 1 left.

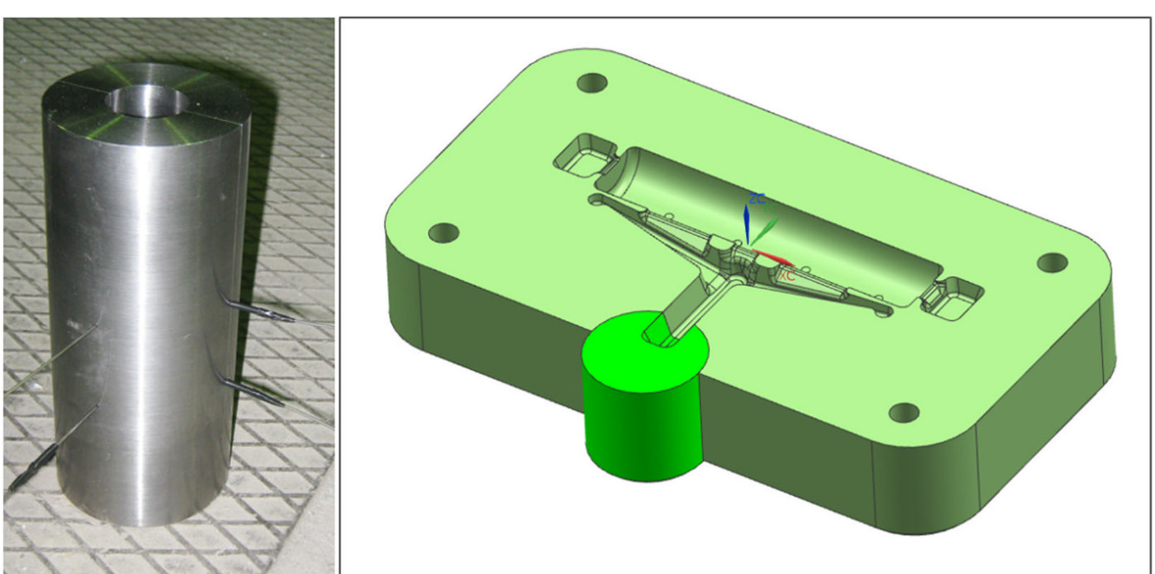

Fig. 1. Instrumented gravity mould prototype (left). Plate of the HPDC mould prototype (right).