NUMERICAL SIMULATION
OF SEMI-SOLID CASTING OF AN AUTOMOTIVE COMPONENT

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ABSTRACT: For setting up innovative processing technologies, such as semi-solid casting, a fundamental contribution can be offered by numerical simulation, which, once correctly elaborated, allows the prediction of fluid-dynamics and thermal fields induced by the process.
This paper is focussed on the study, by means of the MAGMAthixo® module of the MAGMASOFT® code, of the semi-solid casting process of an automotive component (engine bracket). The requirements for a proper development of the numerical model are described and the results of simulation are presented as mass and temperature distributions and compared with the output of experimental processing tests and with microstructural investigations.
The good correspondence between experimental data and numerical simulation results confirms the reliability of this approach in developing processes and products.

KEYWORDS: Semisolid processing, Numerical simulation, Aluminium alloys, Microstructure

1 INTRODUCTION

Aluminium foundry is an industrial field, which is continuously growing, both in terms of productivity and of innovation degree. The recent development of new casting processes for Aluminium alloys and composites is the best example of these potential and creativity [1-3].
Thixocasting processes are become, in the last year, an industrial reality, and allow the production of high quality / high performances Aluminium alloys castings. The principles of semi-solid processing of metals and alloys find the proper industrial application in the automotive field, where a synergetic combination of high production rates, lightweight components and safety requirements is more and more strongly needed.
For different reasons, which are documented in literature [3-11], the introduction of the thixocasting approach, in the scenario of diecasting companies, is not a simple task: it needs a deep knowledge about rheology and solidification metallurgy, to properly re-define process and casting systems design.
A powerful support to the set up of thixocasting processes can be certainly given by another innovative technology, which is actually determining a revolution in the world of foundry: the numerical simulation of process. The application of such a technology, with various successful case histories, is also growing its role. The possibility of pre-viewing the dynamics of cavity filling, of casting solidification and of dies thermal behaviour leads to the individuation of the better process parameters and working conditions, in order to optimise the quality of the components and to increase die life [12-15].
This paper presents the use, and the contemporaneous validation, of the MAGMAthixo® computational code, for the set up of the manufacturing process of an engine bracket, produced, on a prototype scale, by thixocasting of the A357 alloy.

2 NUMERICAL SIMULATION OF THIXOCASTING PROCESS

The component to be produced is an engine bracket; Fig. 1 summarises the path for the production:

a) the bracket 3D geometry, together with the gating system,
b) the 3D mesh, as automatically achieved by the computational code,
c) the as cast bracket.

As previously mentioned, the alloy chosen was an A357 one (Althix 67S1®), which, according to the producer, has an eutectic temperature of 575°C and has to be semi-solid cast at temperatures up to 585°C [16]. It is well known that a key point, for the achievement of reliable results from numerical simulation codes, is the correct definition of the thermophysical properties of the material involved. While, on one hand, there are no problems from the die-side, on the other hand the implementation of the alloy properties is very critical. In detail, even if there are some general rheological models for describing the behaviour of alloys in semi-solid state, there is a lack of specific data. In the present case, the Ostwald – de Waele model was adopted [17-18], which follows the laws

$$\eta = \rho \cdot m \cdot \dot{\gamma}^{n-1} \qquad \text{and} \qquad \tau = -\rho \cdot m \cdot \dot{\gamma}^{n},$$

where ρ is the density, η is the apparent dynamic viscosity, m is the Ostwald-de Waele coefficient, $\dot{\gamma}$ is the shear rate, n is the Ostwald-de Waele exponent, τ is the shear stress. The properties of A357 alloy, according to such model, are implemented in the Materials Database of MAGMAthixo®. The code, obviously, requires also the information concerning the die (a DIN 1.2311 steel has been used) and the process parameters (flow curve, details of the cycle steps, working conditions of the die). Some working cycles were simulated, and the final one was considered as representative of the steady-state process.

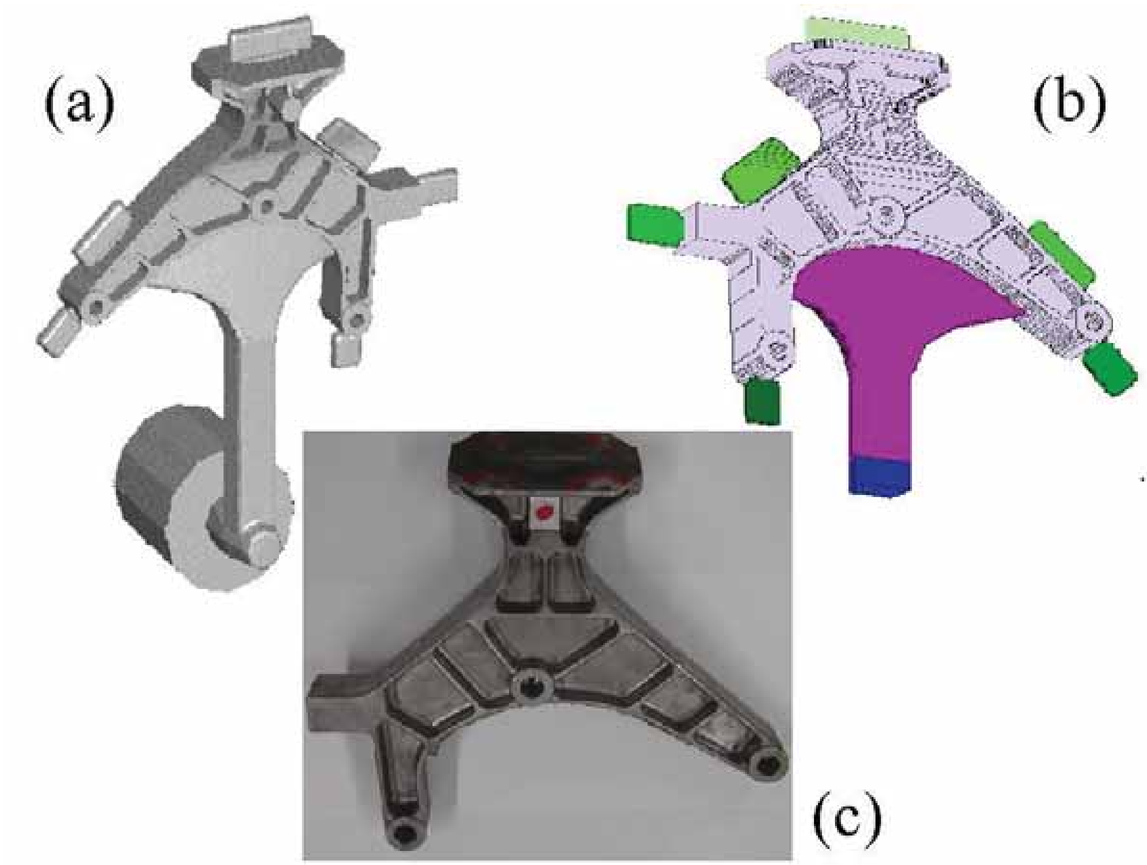

Fig. 1: 3D geometry of the engine bracket and of the casting system (a); 3D mesh developed for the numerical modelling (b); prototype of the engine bracket (c).

3 EXPERIMENTAL VALIDATION OF THE NUMERICAL MODEL

The experimental investigations carried out allowed different levels of validation of the code. The first aspect is certainly the dynamics of cavity filling: the simulation can be compared with the results of interrupted filling tests. The correspondence, as it is shown in Fig. 2, is really excellent, indicating the reliability of the fluid-dynamic model, also for a complex geometry. It is also very interesting the examination of the velocity field established during the process. The velocity values in the filling front (Fig. 3) typically fall in the range 1.0-2.0 m/s, which is in good agreement with the suggestions of the producer (values up to 1.0-1.5 m/s give the filling front a better stability front [16]).

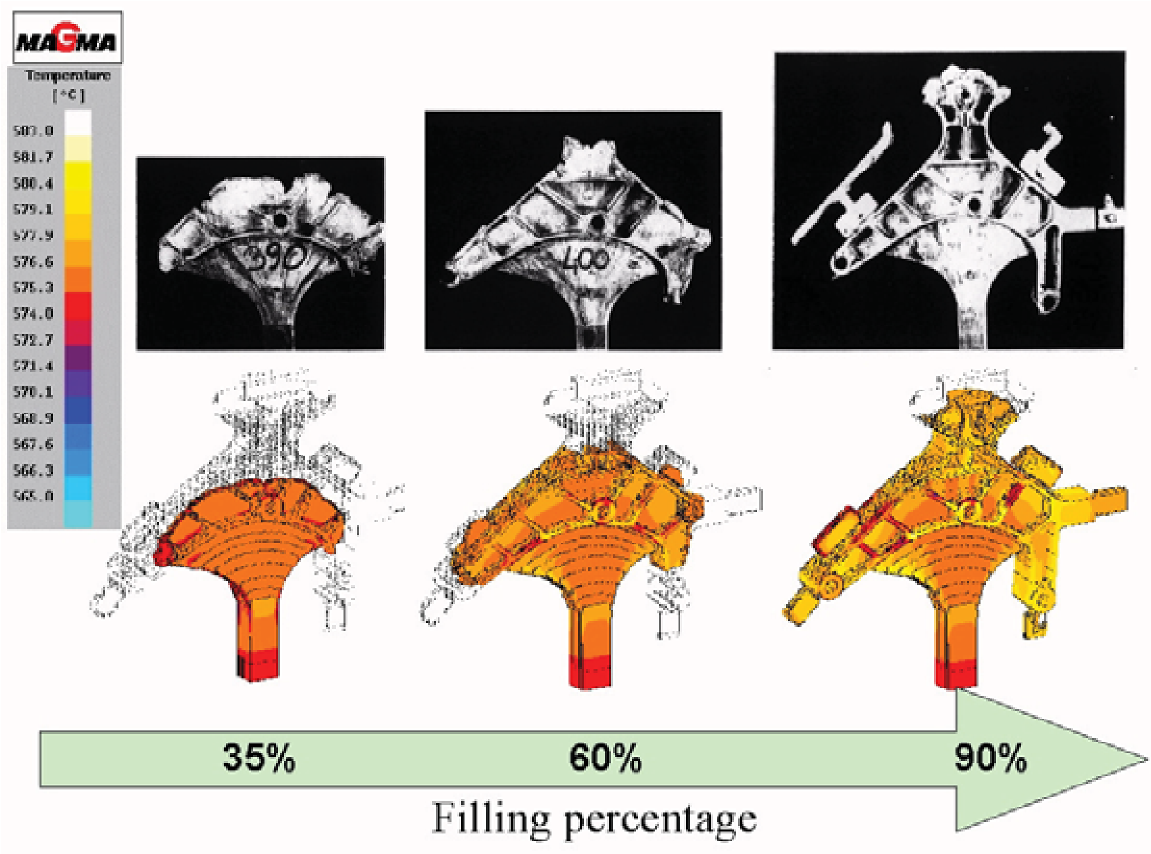

Fig. 2: Filling sequence: comparison between interrupted filling tests and numerical simulation results.

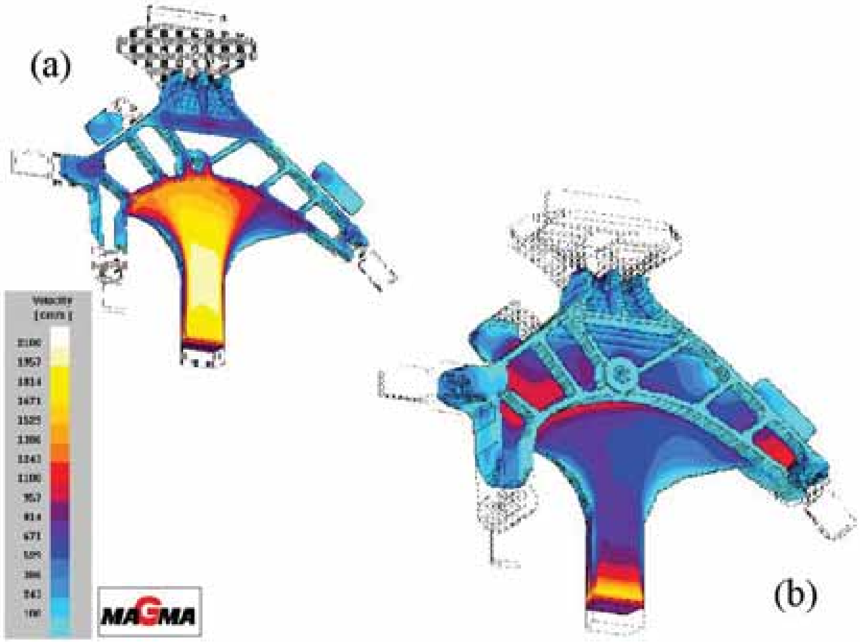

Fig. 3: Velocity field at 70% of filling: section (a) and overall view of the bracket (b).

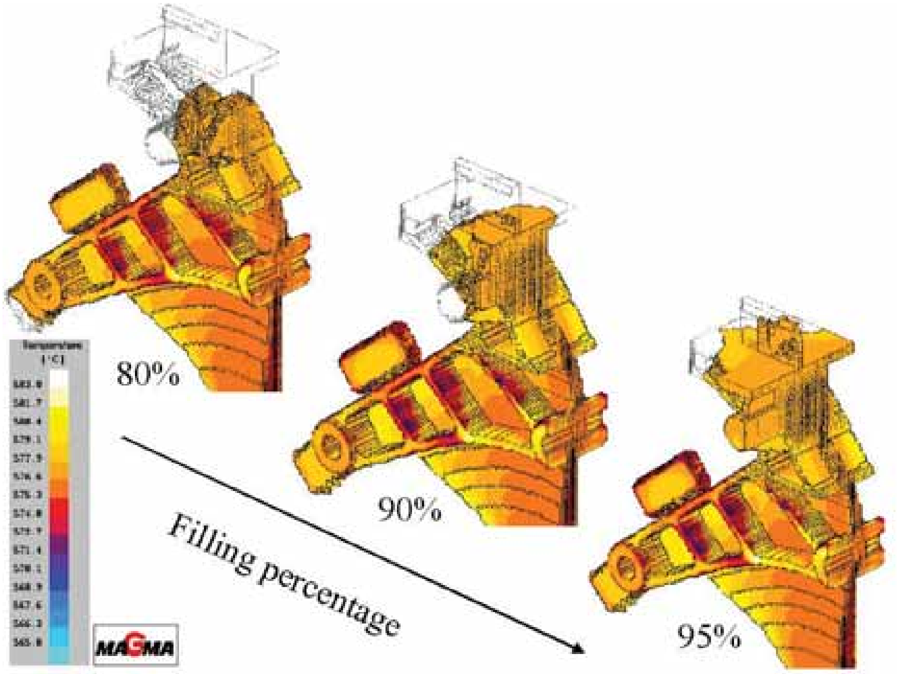

Fig. 4: Final part of filling sequence (upper region of the engine bracket).

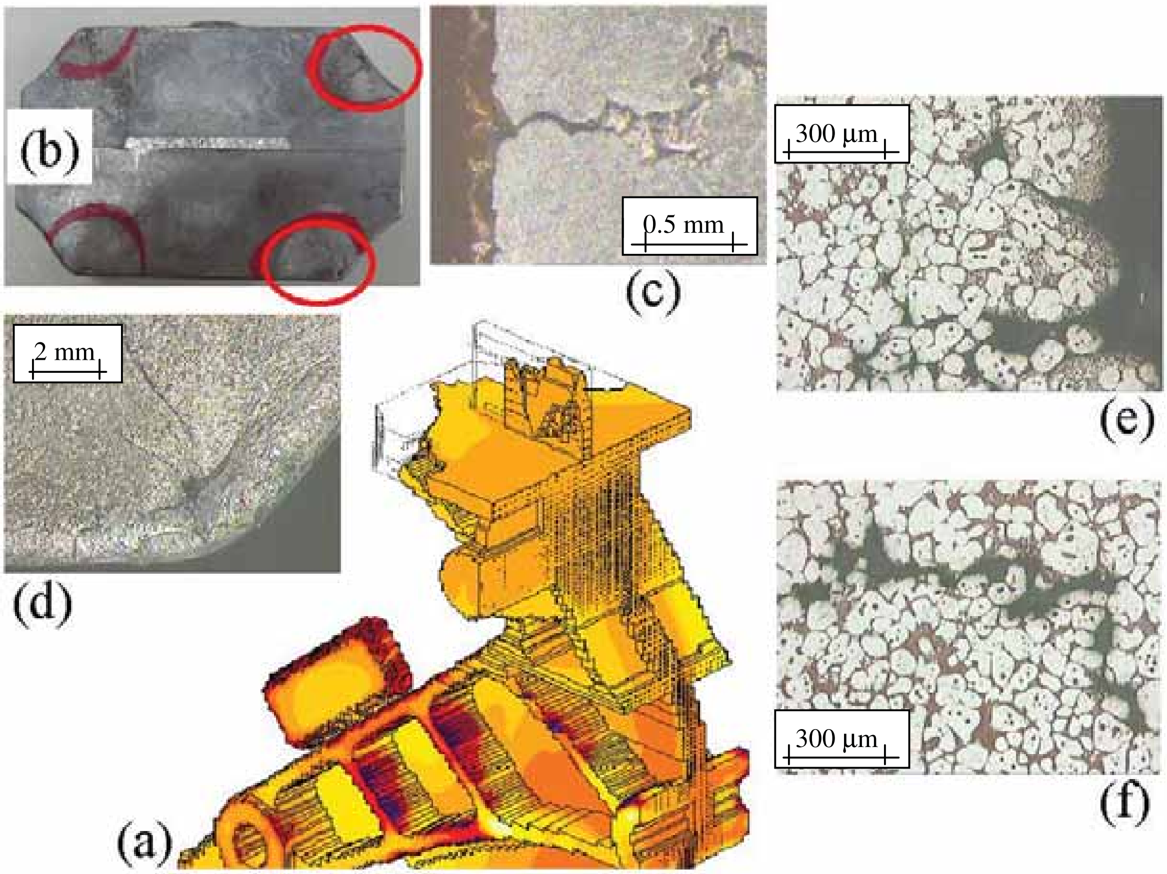

Fig. 5: Final stage of filling in the upper part of casting (a); photo of the upper plate (b); macrograph of surface defects in the plate (c, d); microstructure and presence of cracks in the plate (e, f).

The analysis of the last stages of the filling sequence (Figure 4) indicates that the four edges of the upper plate are the last one to be filled, with a relatively low temperature.
These regions have a high risk of defects (uncompleted filling, splash and shotting, tearing phenomena) as it is well shown in Figure 5.
Finally, from the analysis of solidification times distribution, a region, in the upper part of casting, seems to be a candidate to become a hot spot, being insulated (Fig. 6). The negative consequences of hot spots

(i.e. formation of shrinkage porosity) are certainly minimised by the intrinsic characteristics of semisolid processing of alloys. However, in the central part of the region individuated in Figure 6 and enlarged in Figure 7a, some microporosities have been observed (Figure 7b), localised in the eutectic surrounding the α-phase globules and due to micro-shrinkage phenomena; a few millimetres far from such region, the microstructure becomes again good (as in the other parts of the casting), with no porosity (Figure 7c).

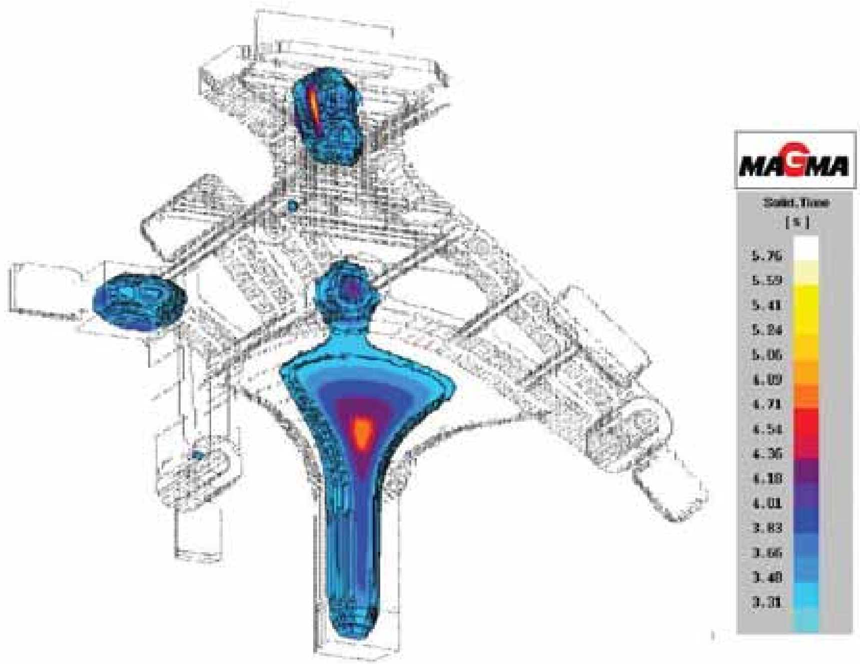

Fig. 6: Distribution of solidification times in the casting.

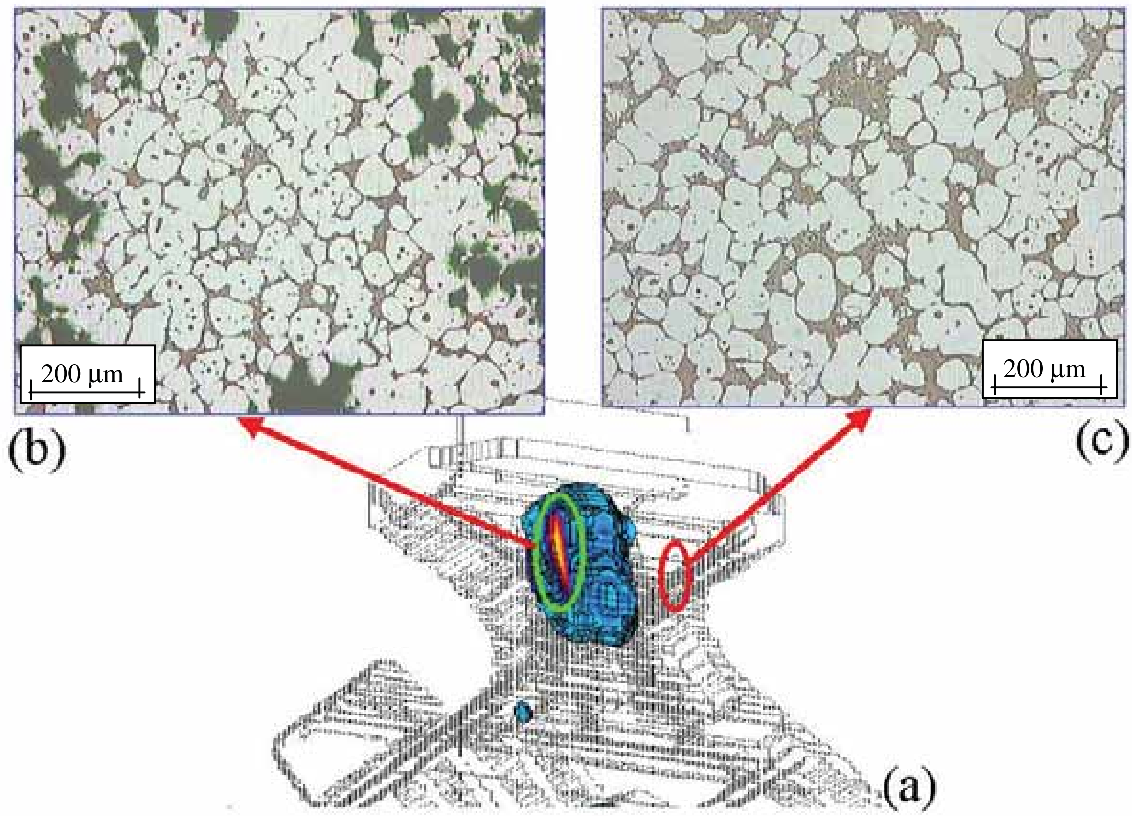

Fig. 7: Upper part of the casting: last region to solidify, as individuated by numerical simulation (a); corresponding microstructure with presence of microporosity (b), compared with that of a region with lower solidification times (c).

Being in the prototype stage, the information coming from simulation can be used to further improve the casting characteristics. In particular, some geometrical changes in the upper part of the casting are suggested: the upper plate should be thickened and rounded, to achieve a more regular filling and to avoid an early solidification of the alloy, which has been verified to lead to significant defects.
From the microstructural point of view, the general good quality of the casting, as experimentally observed, is in agreement with the simulation. An interesting task, which is actually under development [19], is the correlation between calculated thermal field and microstructural parameters (size and shape factors of α-phase globules), to implement the coarsening kinetics laws [20] into a micro-modelling module.

4 CONCLUSIONS

The reliability of numerical simulation applied to semi-solid processing of Aluminium alloys has been experimentally verified on different levels:

- prediction of the flow behaviour during filling of die cavity,
- individuation of the regions with high risk of defects associated to uncompleted filling, hot tearing and splash and shotting phenomena,
- individuation of the regions with possibility of becoming hot spots, i.e. with high risk of micro-shrinkage phenomena, leading to an inter-globular porosity.

These information have been employed to “correct” the design of the prototype die, in order to obtain a casting geometry less sensitive to filling and solidification defects. In this way, numerical simulation has confirmed its potential as an engineering tool also for semi-solid casting of Aluminium alloys.

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