La Metallurgia Italiana
International Journal of the Italian Association for Metallurgy

AM Process Simulation to Optimise Diecasting Tooling

N. Gramegna, D. Boscolo, G. Scarpa, Nardo and F. Bonollo

The innovation of design for diecasting tooling is significantly affected by Additive Manufacturing (AM) technology evolution as well as by the increasing reliability of AM process simulation [3]. The casting process simulation is a well-known standard design procedure to optimize the thermal steady state of each part of the steel die taking into account the limitation of traditional machining process to produce the insert with proper cooling channels [1,2]. The advent of Selective Laser Melting (SLM) or Electron Beam melting (EBM) is opening to free form of cooling channels to control the thermo mechanical behaviour of the steel tooling improving the die life and reducing the risk of local defect in the casting. Further possible development is the application of DED to reparation of the High pressure die casting (HPDC) tooling. The AM simulation tools can simulate different additive processes and various virtual scenarios can be evaluated. The Optimization of diecasting tooling is entering a new era thanks to material, technologies and virtual simulation tool of AM processes.
The study described in this paper is a reference application of HPDC and AM simulation coupling the benefits of the two manufacturing processes. The thermo-mechanical performance of traditional diecasting insert is improved by conformal cooling channels and the cycle time is typically minimized. The SLM simulation validates the 3D printing of steel material taking into account the geometry compensation, the support optimization and the quality of printed part to be treated and machined.
The cost- benefits analysis supports the decision in the design phase validating the optimal geometries for the production of the components, verifying the efficiency of the cooling channels designed to support the quality of the component and the dies life, maximizing the benefits and reducing costs [4].

KEYWORDS: PROCESS SIMULATION, ADDITIVE MANUFACTURING, STEEL INSERT, CONFORMAL COOLING, HIGH PRESSURE DIE CASTING, PROCESS OPTIMIZATION

INTRODUCTION

High-pressure die casting process (HPDC) is one of the most exploited casting processes. Nowadays the process is used more and more to cast multitude of different sizes and far more complex castings. The principle of the HPDC process is that molten metal (mostly aluminum or zinc) is pressed into the cavity under high pressure. The cavity is filled in a few hundredths of a second. After the melt has solidified, the casting is removed from the open die and afterward the cavity surface is sprayed with a die lubricant water based and blown with air to avoid water stagnation. The die is then closed and ready to receive a new portion of molten metal. The permanent die undergoes severe thermal cycles, since the range of temperatures involved and the little cycle time. Thermoregulation during the heat removal is crucial not only to obtain a good quality part, but it also affects the die life and the production time cycle, cost-effectiveness of

N. Gramegna, D. Boscolo, G. Scarpa
Enginsoft Spa, Italy

N. Nardo and F. Bonollo
University of Padova, Italy

the process results strongly dependent onto these factors.
HPDC dies are made of hot working steel, such as H11 and H13. The complex cavity shape is conventionally obtained with machining processes (CNC, drilling, ...), thermoregulation circuits are so restricted to straight line shapes. Thus, meaning that conventional thermoregulation circuits don't impart optimal thermal (and thermomechanical) behavior, especially in case of great complexity of the cavity (such as curved-in shapes, thin thickness inserts, ...). The advent of Additive Manufacturing (AM) for metals, and its consolidation declined in the Powder Bed (and Direct) methods, has paved the way for an innovative way of tooling, opening many possibilities on different levels. The design is freed from conventional tooling (machining) constraints, the material usage is lowered abandoning the subtractive conventional processes, design and different processes and scenarios can be easily evaluated through increasingly reliable simulation means.
Conformal Cooling technique takes advantage of AM characteristics listed above, die inserts can so be equipped with free form and small diameter (down to 1.5 mm) cooling channels, enabling the redesign of the conventional die inserts, making feasible a much finer control of the thermomechanical behavior of the die. While the literature already explored and proved the value of applications of AM tooling for injection molding, it appears to be still pretty unexplored for HPDC. The aims of this paper are to:

- build a DOE Analysis of conformal cooling application to an HPDC die insert to figure out the best alternative among the proposed layouts;
- Assess techno-economical costs and benefits of a conformally cooled insert in comparison to a conventional insert;

The expected benefits introducing 3D printed inserts in the traditional HPDC tooling are the reduced cycle time (less solidification time), best casting quality (less defects) and prolongation of die life (less stressed tooling).
To carry out this analysis in this paper simulation tools will be deployed. In particular thermal behavior of the insert and part quality will be evaluated through the utilization of MAGMASOFT®, while AM feasibility will be assessed through the Ansys® Print suit.

CONFORMAL COOLING DESIGN

After the analysis of the conventional design it appeared that the main issue of the HPDC castings was to be found in localized porosity. To solve this issue four inserts where selected to be candidates, on their own or in different combinations, for conformal cooling circuits. The first of this insert is an actual separated insert already existing on the slider, the other three inserts where derived respectively one from the fixed and two form the ejector die. Due to the narrow dimensions of the spires of the three inserts on ejector and fixed die only one conformal cooling was designed for each, while with a bigger available volume eight alternatives have been designed for the side core insert.

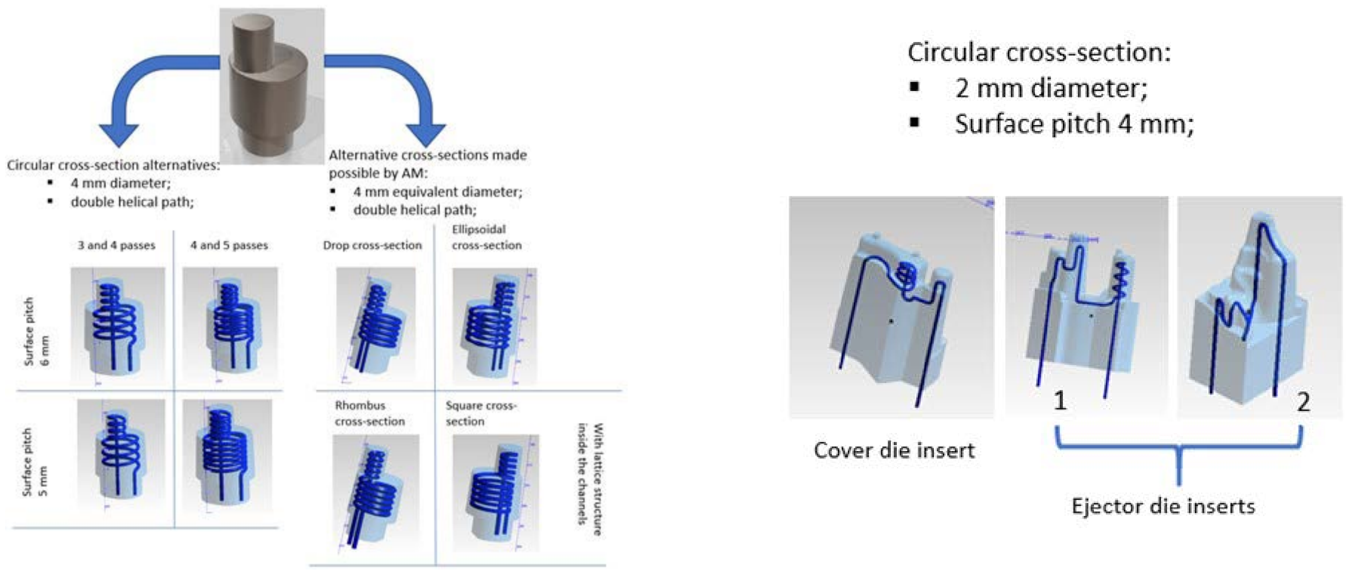

Fig.1 - Conformal cooling proposed designs.

THERMAL ANALYSIS

To evaluate the best alternatives a full factorial DOE was set up based on the created designs. Four factors were defined, three factors were set as the three circuits designed for ejector and cover die were set to be either active or not, the fourth factor took into account the side core insert, in its eight circuit designs plus the possibility of absence of any cooling circuit there. Four objectives have been set to minimize: porosity, porosity on an evaluation area, FS time and the sum of the active circuits. This generated 81 alternative designs, in table 1 the improvements of the DOE winning design in comparison to the conventional one; the winning design is characterized by 2 conformal cooling circuits: rotating ellipsoidal circuit for the side core die and the circuit of the ejector die insert 2;

Tab.1 - Achievements of conformal cooling in comparison to the conventional design.

	Δ% porosity	Δ% Temperature	Δ% cycle time	Δ% productivity
Conformal Cooling Design	-95%	-77.84%	-16.47%	+19.72%

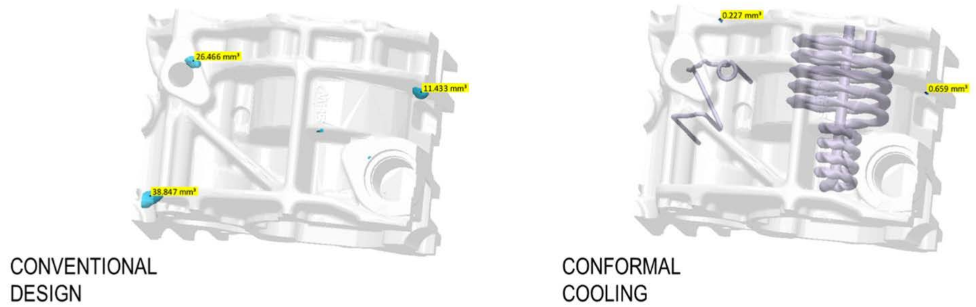

Fig.2 - Critical porosities reduced using conformal cooling.

In addition to these results the die life of the side core insert was evaluated, showing impressive improvement too;

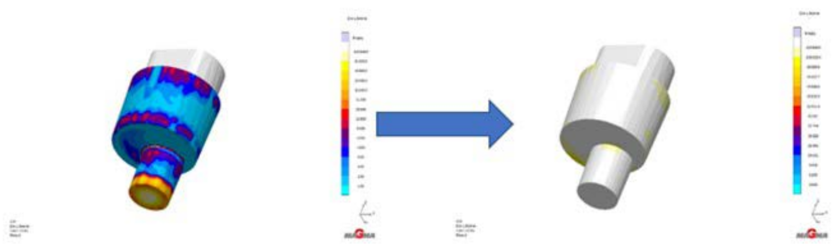

Fig.3 - Die life results improvement: on the left conventional design on the right conformal cooling design, showing a much longer die life duration through the colors on the top of the scale representing the number of cycles.

CFD ANALYSIS

The production process analysis took into account also the fluid dynamics of the circuits (cfd analysis). Thanks to the definition of the medium, the medium temperature and the flow rate, it is possible to evaluate the efficiency of the circuits and possible leaks.

In this specific case, water at 20 ° c with a flow rate of 20 l / min was the considered medium.

The results show in particular that the thermal delta between input and output does not exceed 5 ° c, indicating a high efficiency of both circuits.

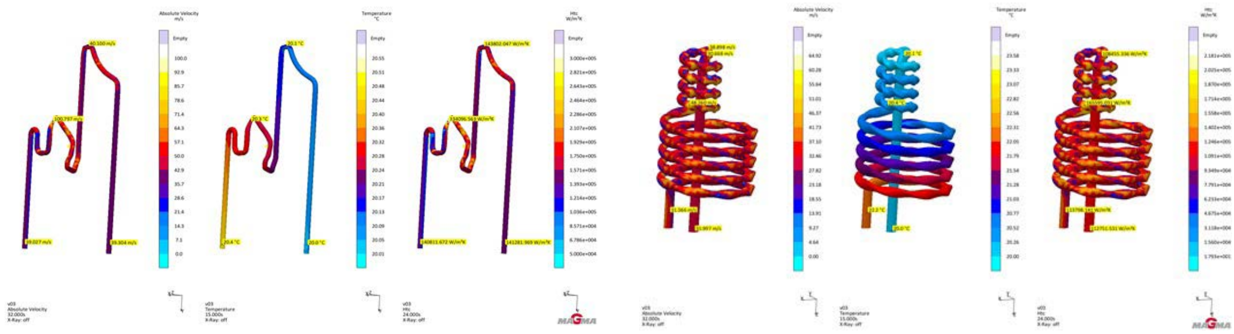

Fig.4 - Conformal cooling cfd analysis: velocity, temperature and HTC results.

AM FEASIBILITY

For evaluation of manufacturability through L-PBF process of the inserts designed one relevant alternative was selected to be simulated, the side core insert equipped with the rotating ellipsoidal circuit. As already mentioned, the simulation of AM process will remain on a macroscopic scale. Exploiting Inherent Strain method, which is based on the strains evaluation. Lack of resources lead to impossibility to calibrate the material and strain scaling factors, therefore the results of this analysis give a qualitative idea of the most critical areas for deformation and stress, more than accurate magnitudes of these. The simulation enabled though, the construction of a compensated geometry and assessed the feasibility of the channels showing acceptable values of stress and deformation along the conformal channels.

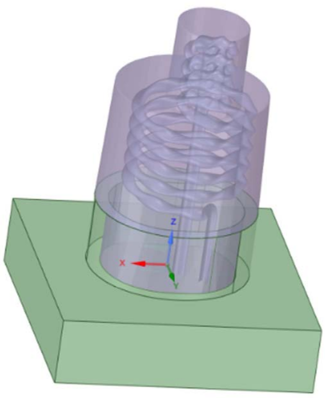

Fig.5 - Conformal cooling cfd analysis: velocity, temperature and HTC results.

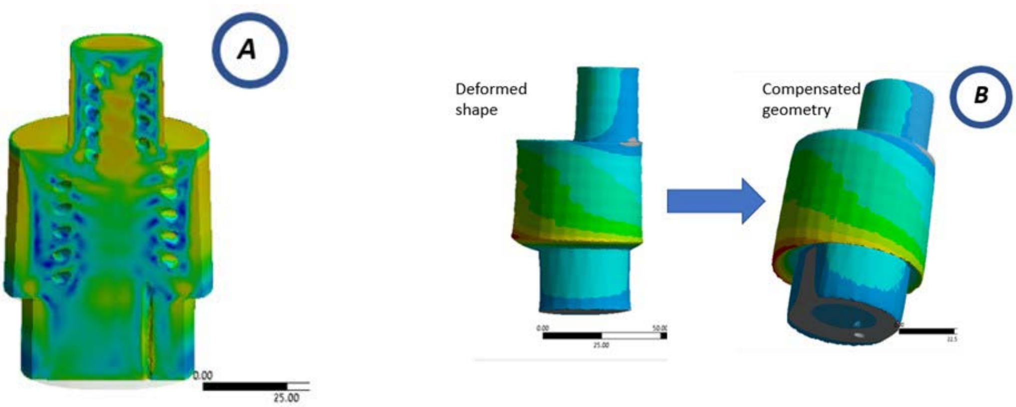

Fig.6 - Conformal cooling cfd analysis: velocity, temperature and HTC results.

COST/IMPACT ANALYSIS

The cost of a L-PBF produced insert is almost 10 times the cost of the same insert produced through conventional tooling due to:

- Numerical evaluation Production cost 1.6 times higher
- Energy consumption 1.8 times higher
- Powder alloy costs 10 times higher than the same solid material

But the higher production cost is justified by the following improvements assessed through simulation:

- the waste castings rate is expected to decrease from a 50% to a 10%;
- the down time for insert substitution considering a production of 1000000 of castings is lessened of the 100%;
- the reduction of the solidification time and therefore cycle time reduction enables a rise of 19% of the production rate;

CONCLUSIONS AND FUTURE PERSPECTIVES

Numerical evaluation of conformal cooling solutions for HPDC die inserts and L-PBF manufacturability of the have drawn an interesting scenario for the future application of these techniques and process in the industry. The most relevant achievements can be divided in two main categories:

1. HPDC process improved cost-effectiveness
2. AM manufacturability of HPDC die inserts

The first point may be considered achieved thanks to two aligned results. Firstly, the higher effectiveness of the HPDC manufacturing process is to be found in the improvement of the part quality, assessed by the reduction of the values of porosity, hot spot and die soldering effects. Secondly cost reduction of the process is to be found in the cycle time reduction, enabling a higher productivity and in the elongation of the die inserts through smaller thermal cycles, lessening hence the down time for insert substitution.

The second point more specifically deals with the L-PBF manufacturability, which has been tested in terms of part deformation and residual stress and strains. The results of the set of AM simulations gave the basis to part compensations in order to obtain a printed part respecting the demanded specifications.

REFERENCES

[1] J. Meckley and R. Edwards, "A Study on the Design and Effectiveness of Conformal Cooling Channels in Rapid Tooling Inserts," Technol. Interface J., vol. 10, no. 1, pp. 1523–9926, 2009.

[2] H. S. Park and N. H. Pham, "DESIGN OF CONFORMAL COOLING CHANNELS FOR AN AUTOMOTIVE PART," Int. J. Automot. Technol., vol. 10, no. 1, pp. 87–93, 2009.

[3] Y. Wang, K. M. Yu, C. C. L. Wang, and Y. Zhang, "Automatic design of conformal cooling circuits for rapid tooling," CAD Comput. Aided Des., vol. 43, no. 8, pp. 1001–1010, 2011.

[4] K. M. Au, K. M. Yu, and W. K. Chiu, "Visibility-based conformal cooling channel generation for rapid tooling," CAD Comput. Aided Des., vol. 43, no. 4, pp. 356–373, 2011.

[5] S. A. Jahan, T. Wu, Y. Zhang, J. Zhang, A. Tovar, and H. Elmounayri, "Thermo-mechanical Design Optimization of Conformal Cooling Channels using Design of Experiments Approach," Procedia Manuf., vol. 10, 2017.

[6] S. Jahan and H. El-Mounayri, "A Thermomechanical Analysis of Conformal Cooling Channels in 3D Printed Plastic Injection Molds," Appl. Sci., vol. 8, no. 12, p. 2567, 2018.

[7] A. Agazzi, V. Sobotka, R. Legoff, and Y. Jarny, "Optimal cooling design in injection moulding process-A new approach based on morphological surfaces," Appl. Therm. Eng., vol. 52, no. 1, pp. 170–178, 2013.

[8] Maciej Mazur Martin Leary Matthew McMillan Joe Elambasseril Milan Brandt, "SLM Additive Manufacture of H13 Steel with Conformal Cooling and Lattice structures Nomenclature," Rapid Prototyp. J., vol. 22, no. 3, 2016.

[9] M. Mazur, P. Brincat, M. Leary, and M. Brandt, "Numerical and experimental evaluation of a conformally cooled H13 steel injection mould manufactured with selective laser melting," Int. J. Adv. Manuf. Technol., vol. 93, no. 1–4, pp. 881–900, 2017.

[10] A. T. Pradeep, "HPDC Die design for Additive Manufacturing," 2018.

[11] N. Nardo, "Optimization of a die insert produced through metal powder bed fusion", 2020, http://tesi.cab.unipd.it/63823/