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FOCUS ON DEVELOPMENT OF QUALITY, HIGH PRESSURE DIE CASTING PROCESS

In contemporary high-pressure die casting foundries, the mastery of each sequence in the production cycle is more and more important. In the paper, an example of virtual analysis of gearbox casting from Al alloy will be presented. It includes a large variety of parameters, as follows: choosing of appropriate foundry technology, calculation of computer simulation of casting process which takes into account the filling process of cold chamber and filling of cavity, model description of three phases in high-pressure die casting, flow of molten metal, solidification, formation of stress and deformations. Additionally, the optimization of cooling and heating systems will be compared with calculated volume defects, dimensions of castings and their deformations with experimentally obtained values.

Keywords: numerical simulations, die casting, development of casting technology, HPDC optimization

1. Introduction

High pressure die casting (HPDC) is widely used in automotive industry for the production of different components. HPDC is ideal technology for high volume production and because of the fast cycle times it is appropriate for thin walled castings too. In such process, the molten metal/alloy is introduced into the steel made die cavity at high speed and under high pressure. The quality of the produced castings is influenced by different technological parameters: the rapidity of the pressing during the casting, the temperature of the cast alloy, the temperature of the die during the cycle, the temperature of the casting cavity, solidification time are only the most important factors.

More or less 70% of aluminium components are produced through HPDC, because of the high production efficiency and near net shape fabrication possibility. Massive components (more than 15 kg weight), i.e. gearbox housings and engine blocks are typical components manufactured through this technology [1-3].

Additionally, for an excellent casting quality it is useful to consider also the residual humidity after lubrication, the level of the porosity developed following the elimination of the gas during filling, acceleration of the pistons, etc. Development of casting defects are directly correlated to a non-appropriate casting procedure, therefore monitoring the whole process is of primary importance.

Industrially, the use of hot work tool steel for die production is a common feature. The manufacturing of dies is a very complex route which starts in the melting shop of a steel mill and continues through refining processes, forging and heat treatments to attain a uniform material.

Finally, the die is formed using mechanical and electromechanical machining methods, where the machining parameters can be correctly regulated to avoid any change in the surface morphology of the steel. Hot work components are generally affected by failure mechanisms such as erosion, corrosion, wear, fatigue, which directly involve the surface. For all these reasons, engineering studies are developed to modify the surfaces either by the application of protective hard coatings or diffusion treatments [4-6]. The dies used for HPDC process have to be resistant to thermal shock and to softening at high temperatures too. Generally, H11 and H13 are the most commonly used hot work tool steels, because they are dimensionally stable and show high hot yield strength; their durability can be associated to the casting temperature, to the thermal gradients into the die and to the level of the exposure to high temperature.

An external thermal balance can be realized through lubrorefrigaration cycle [7]. Generally, to have a good surface quality, one can consider the geometry of the piece and some parameters related to the production features. The casting temperature, the temperature of the die walls, the pressure and the geometry of the piece to be casted are some of the parameters influencing the solidification time. These parameters have to be considered for the calculation of the cooling time, which has to be the most appropriate one in order to maintain a good dimensional stability, but industrially the tendency is to extract earlier (at high temperature) the component to save some time on the process cycle at the cost of lowering the dimensional quality of the end product.

In this paper, the attention will be oriented to the optimization of the HPDC process for aluminum alloys, to improve the reliability of the process and the quality of the castings using

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a low cost procedure in an environmentally suitable way. In particular, the thermal balance of the die through an appropriate control and setting of the lubricant application with a simultaneous refrigerating effect is considered and presented.

2. Experimental

Table 1 and 2 report the composition of the Al alloys and the composition of the hot work steel, commonly used for manufacturing of dies for forging and die casting of light alloys, respectively. The hot work tool steel is being hardened by austenitizing at relatively low temperatures (about 850°C), obtaining a good dimensional stability and the resistance to thermal fatigue cracking.

The casting integrity and internal porosity has been detected by radiography and radioscopy tests using X-ray systems, for the casting quality evaluation Coordinate Measuring Machines has been used. Optical and Scanning Electron Microscpy (OM, MeF4 Reichart-Jung model, SEM, LEO 1450 VP model) equipped with Energy X-ray Dispersive Spectroscopy unit (EDS, Oxford microprobe) has been employed for microstructural analysis. To reproduce as much as possible, the real conditions during lubro-refrigeration of the dies, a heated laboratory sample was used. Heating is carried out in a preheated furnace (model Warmy 9V). Thermocouple type K were embedded into the plate, in the region encircled in Figure 1 (right), for the monitoring of the temperature and connected to a control unit. Data acquisition over time was performed using a data recorder (TC-08 type), while a thermal imager (PI160 di Optris type) was used for the detection of the temperature on the surface of the sample and its variation following spraying with lubro-refrigerant liquid.

The whole non-standard system schematized used for the test is reported in Fig. 1 (left hand side), while a sample reported and the position of the thermocouple is illustrated in Fig. 1 (right hand side).

As visible from the Figure 1 the depth of the hole for the thermocouple are different (4, 8, 12 mm) in order to better appreciate the dispersion of the heat inside the sample.

The edges of the samples were sealed with silicon to protect them during spraying. The experiment was performed using the following test conditions:

- the spray nozzle was sited at 100, 200 and 300 mm away from the test plate and was oriented perpendicularly to the core of the sample;
- the pressure was maintained at 4.5 bar in all experiments;
- the time of the spraying was prefixed to 1, 2.5 and 4 s;
- the die temperature was 100, 250, 330°C.

3. Results and discussion

The component produced through HPDC is a gearbox, which has a remarkable size for the employed technology and shows a particularly complex geometry. The component shows

TABLE 1

Chemical composition (wt %) of the EN AC 46000 alloy

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Pb	Sn	Ti	Other	Al
EN AC 46000	8-11	1.3	2-4	0.55	0.15-0.55	0.15	0.55	1.2	0.35	0.15	0.2	0.25	Bal.

TABLE 2

Chemical composition (wt %) of the AISI H11alloy

Alloy	C	Si	Mn	P	S	Cr	Mo	Ni	V
AISI H11	0.39	0.97	0.43	0.015	0.006	5.01	1.14	0.21	0.35

Fig. 1. Setup for the measurement (left) and the laboratory sample with indication on the position of the thermocouple (right)

unexpected section change, then thin and thick portions undergo to a non-uniform cooling. For these reasons and considering the dimensional modifications in all directions, non-uniform thermal contractions occur, compromising the dimensional stability of the component. For improved quality castings it is required to obtain the best thermal homogeneity within the die in order to allow a rapid and uniform cooling of the casting. The first step in this study was to check the quality of the casting and to analyze the wear of the die. Development of the internal porosity has been detected (Fig. 2a,b) which corresponds to shrinkage porosity (Fig. 2c) and vapor entrapment porosity generated as a consequence of the residual humidity of the die (Fig. 2d) after a more detailed SEM analysis mixed porosity. Occasionally some mixed type porosity has been observed, which are intrinsically generated during casting processes.

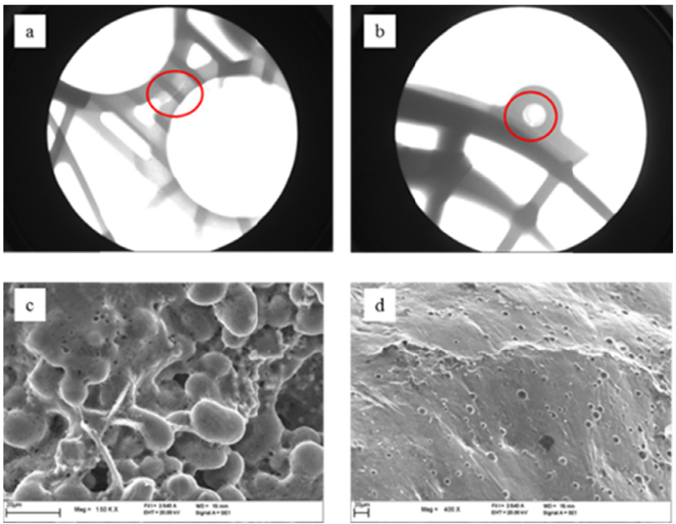

Fig. 2. X-ray radioscopic observation showing the presence of defects (a,b) and SEM images showing in detail the nature of defects (c,d)

The visual inspection of the die, after about 150.000 production cycle, is reported in Fig. 3. The circled area is situated close to the casting in-gate and faraway from the feeder head and can be considered as a critical position, because of the complex geometry, where predominantly wear and erosion act.

Fig. 3 Photograph of the damaged portion of the die

One has to consider some direct and some indirect problems: (i) the former one is generated from the component design, which shows an unexpected variation of the direction, therefore the liquid metal at about 685°C hits quasi perpendicularly the die surface and (ii) the second aspect is related to the higher turbulence of the liquid metal near to the considered area, caused by the quasi angle of 90° within the sprue. By re-evaluation of the die design it would be possible to correct this particularity. As for the process parameters concern, the main important factors connected to such a high wear are the velocity of the liquid metal and the temperature of the die. By performing an accurate die-filling simulations a velocity of 70 m/s near to the casting in-gate (Fig. 4 left) has been obtained. To reduce the effect of erosion generated from a too high velocity of the metal it is necessary to maintain the temperature of the die surface as high as possible (about 250°C) and to develop a uniformly distributed lubricant on its surface. The detected temperature in this point is 115°C (Fig. 4 right), considerably lower than the recommended temperature able to minimize the thermal wear and the development of a uniform lubricant layer. Actually, to minimize such outcomes, some investigations have been carried out on a laboratory samples (72×84×22 mm^3) concerning the main parameters associated to the lubro-refrigeration phase, where the geometry of the die has not been considered. In such a way,

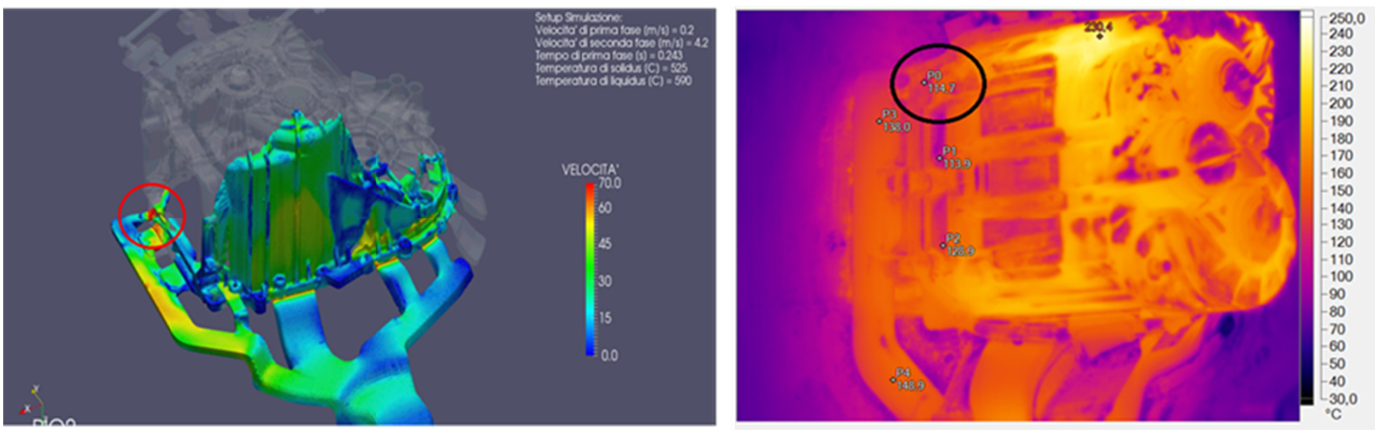

Fig. 4. Die-filling simulation result (left) and the recorded temperature of the die (right)

once the results are validating there are the possibility to really use the outcomes of the study for different industrial processes. In this study, application of a design of experiments (DOEs) has been used for analysing the influence of some parameters on the internal quality of the casted parts. The obtained results have been evaluated, in order to assess how the variation of the parameters, namely temperature of the die surface, spraying distance and spraying time, affect the quality of the casting. The spraying pressure and the orientation of the spray nozzle has been maintained constant. DOE has been generated using Minitab17 software to identify and to randomize the experiments carried out for the development of the model which sufficiently describes the evolution of the thermal flux for the different combinations of the considered parameters. The parameters employed for the experiment are reported in Table 3.

TABLE 3

Parameters used for the experiment

Die surface temperature (°C)	200	250	330
Spraying distance (mm)	100	200	300
Spraying time (s)	1	2.5	4

A clear evidence about the considerable effect of the spraying distance and spraying time on the temperature after lubrication of the surface was obtained, as reported in Figure 5. Maintaining the sample at about 330°C and varying the spraying distance and the time of the spraying a significant difference on the temperature variation is obtained: when the time increases and the distance decreases, the temperature variation on the surface of the die significantly increases. On the contrary, in case of a constant spraying distance, spraying time and lower surface temperature, before and after lubro-refrigeration, there are no substantial temperature variations.

4. Conclusions

In this paper, some important features related to High Pressure Die Casting for Al alloy were presented.

The paper aimed to highlight the influences of the different process parameters on the quality of the casting and to present some preliminary results about the improvement of the quality of the casting through an appropriate control and setting of the lubrication with a simultaneous refrigerating. The experimentally obtained results revealed that the spraying distance and the spraying time influence the temperature distribution within the analysed sample: lower surface temperature and constant spraying distance and constant spraying time determine insignificant temperature variation between lubro-refrigerated and

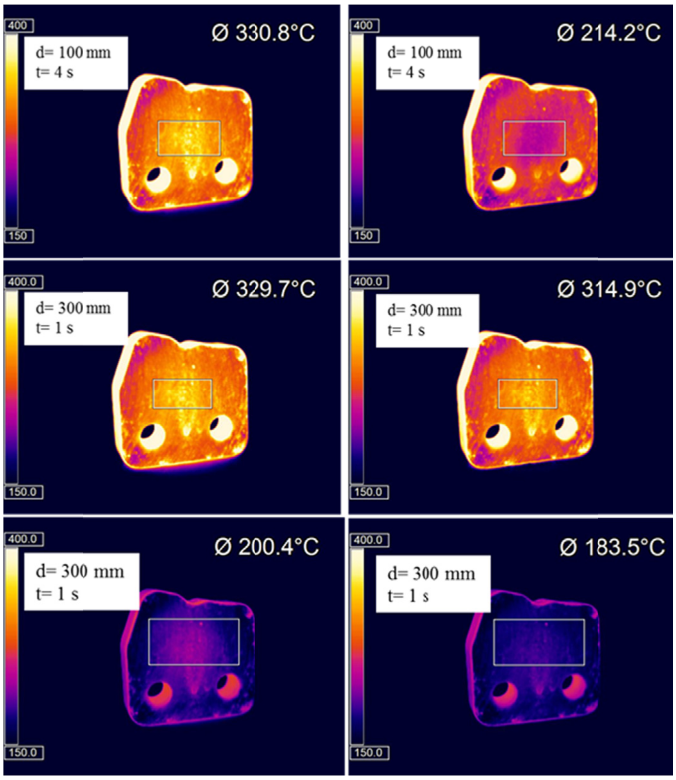

Fig. 5. IR thermography of the sample before lubro-refrigeration (left) and after lubro-refrigeration (right) for the different considered conditions

un treated samples. Some on-going research are directed to the evaluation on the effects of the single parameter on the surface die temperature and on how the application of lubro-refrigeration influences the heat transfer in Al alloy castings.

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