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Effect of Cavitation Phenomenon on the Quality of High-Pressure Aluminium Alloy Castings

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Abstract

This article presents an analysis of the effect of cavitation on the erosion of pressure moulds intended for the HPDC casting mould manufacturing process. Changes in the surface area of the eroded areas were investigated via photographs of castings at the beginning of the mould life as well as at 30%. The individual process variables were described and their influence verified via the cavitation potential module of the Flow3D simulation programme. The results are presented graphically with a description of the relationships and observations. The summary provides an explanation of the results and the dependencies that occurred.

Keywords:

foundry, aluminium alloys, cavitation, casting defects, simulation

1. INTRODUCTION

High-pressure casting, due to its production characteristics (high process efficiency) and advantages such as dimensional accuracy and stability, and very good surface finish, is the leading technology for casting [1, 2]. This contributes to the choice of high-pressure casting as the main casting method in the context of high-volume production. As interest in this method of casting production is increasing, so to is the complexity of projects implemented via die casting. As the main customer for die casting is the automotive industry, manufacturers are faced with the need to select increasingly demanding technology to meet market expectations. While using advanced technologies, at the same time as increasing process requirements, undesirable effects can occur, the phenomenon of which itself is not obvious and the reasons for its appearance are ambiguous [3–5].

One of the basic conditions for obtaining die castings with the required quality parameters is to minimise air occlusion and to fully control the filling phase of the mould cavity with the liquid casting alloy. Minimising the contact between liquid aluminium and air is a guarantee of high strength properties and low porosity [6, 7]. These measures are implemented in several stages. One example is Parashot technology. It is based on the time-varying speed of the piston in the first filling phase, consisting of a smooth initial movement and constant acceleration. This results in a continuous increase in metal velocity, creating an accelerating wave of aluminium [8]. Due to the varying cross-sections in the gate system, the velocity increases until close to the gate gap, where the start of phase II, the filling of the mould cavity, takes place [9, 10]. In this way, the aluminium moves in a laminar fashion and the continuity of the velocity increase results in an inability to switch to turbulent flow and increase air contact. Another translation of eliminating air contact with the liquid metal is the use of reduced pressure in the cavity [11]. This allows the better evacuation of air and gases through the vacuum created in the die cavity before and during injection of the liquid metal. As a result, foundries are increasingly retrofitting their machines with vacuum systems [8, 12]. In addition to the many advantages, the problem of premature mould erosion occurred in the case studied after the application of vacuum. After analysis, the occurrence of a cavitation problem was demonstrated. This phenomenon, not only in die-casting but also in other industries where conditions are favourable to its occurrence, is the cause of the premature erosion of tools and deterioration of their working conditions [13]. Unlike the moulds used in traditional casting, which are based on classic moulding materials, the cost of a mould in a die-casting machine represents a large percentage of the total project. The mould must be able to withstand several hundred thousand castings in an unaltered state (within the appropriate tolerance range). Therefore, the phenomenon in question is a highly unfavourable, undesirable factor that is also very difficult to predict [14]. This paper presents an attempt to find the root cause of the problem of premature mould erosion, which resulted in a costly regeneration of the tool at 30% of its declared service life.

2. RESEARCH METHOD

The aim of the study was to determine the cause of the mould failure in the selected section, based on casting analysis and simulation. The suspected cause is the effect of the cavitation phenomenon. In addition, an analysis of the influence of individual process parameters on the cavitation tendency was carried out on a selected design example. Figure 1 shows the design of the analysed casting system.

a)

b)

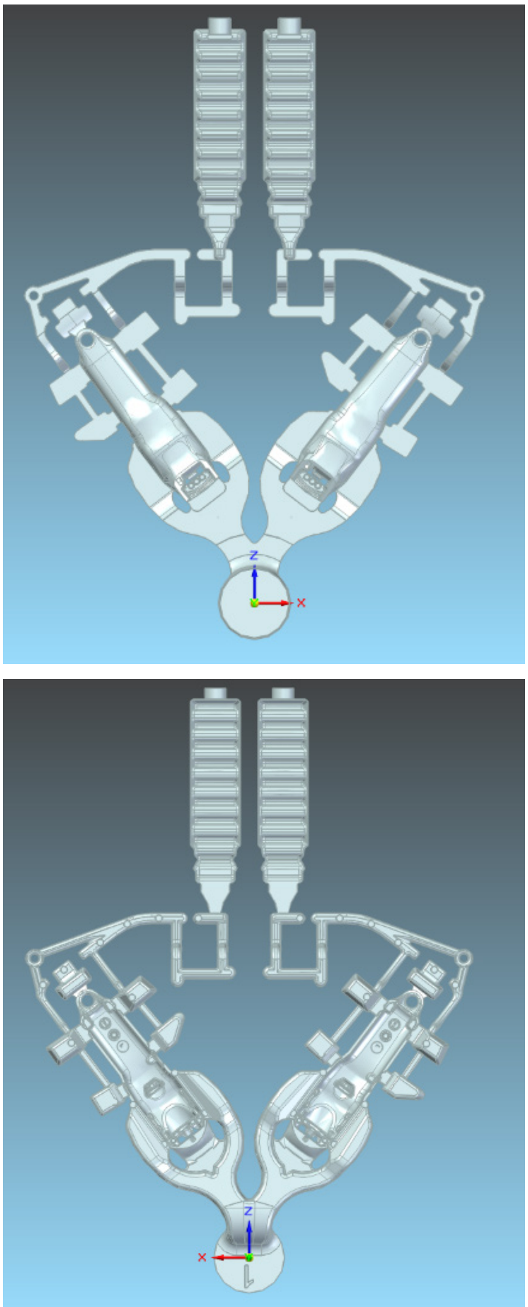


Fig. 1. Photograph of the project under analysis. View: a) from the fixed half; b) from the mobile half

A thermal imaging analysis is shown in Figure 2. It allows quality critical points in the mould to be observed.

In this project, a vacuum generator was used in the casting process to reduce the gas/air pressure in the mould cavity to facilitate the removal of gases from the mould cavity.

a)

b)

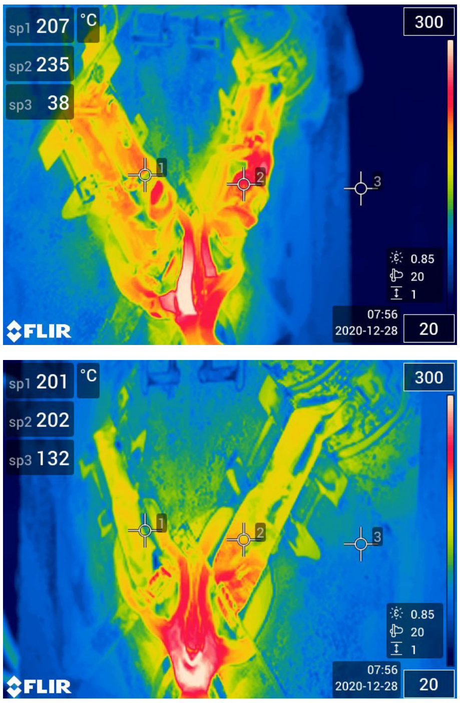


Fig. 2. Thermal images of the mould used in the study: a) fixed half; b) mobile half

3. EXPERIMENT

Due to the conditions of die casting, there are times when the metal pressure locally drops several atmospheres below the evaporation pressure during the filling of the cavity. Such events usually occur at the filling cavity where the metal flow velocities are highest. Under such conditions, the phenomenon of liquid metal cavitation occurs, which in turn contributes to mould erosion. The propensity for cavitation in die casting can be analysed by simulation using the 'cavitation potential' model as an element of the Flow3D-cast software [15]. This method allows the detection of areas where cavitation bubbles are likely to nucleate, rather than the area of their implosion. This means that the areas shown by the Flow3D simulation module do not define the specific locations of the flaw. They indicate areas where conditions are created that favour the onset of the cavitation phenomenon. Figure 3 shows the result of the input simulation.

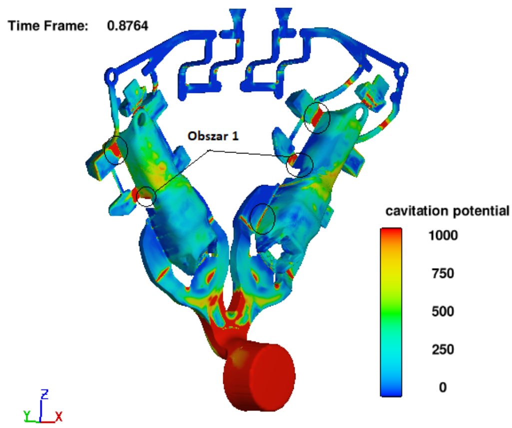
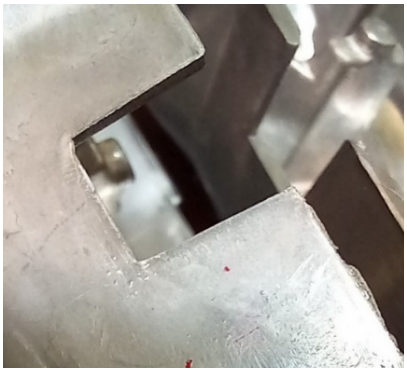


Fig. 3. The result of an input simulation

Figure 4 shows images of the mould after 300 and 29100 injections.The difference between the photos after 300 injections and those after 29,100 clearly shows an increased degree of mould degradation. The degraded areas are located at the overflow slots, in the shadow of the feed gate, on sharp edges, perpendicular to each other. This design forces a rapid change in the direction of metal flow.

a)



b)

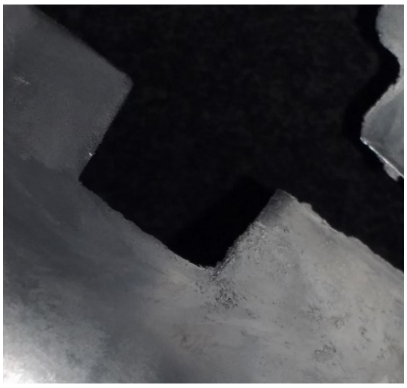


Fig. 4. Summary of visually inspected areas of the casting made at the beginning of the mould life and at 30% of the life: a) 300 injections; b) 29,100 injections

From the results of the tests and analyses carried out, it can be concluded that the defects described, which contributed to the premature wear of the mould, are the result of the phenomenon of cavitation. The differences in the areas of defect occurrence between the cavities are due to the lack of symmetry of the entire casting branch, which means that the left-hand casting is filled differently from the right-hand casting. The areas most prone to cavitation are those with sudden, rapid changes in flow direction and velocity (Fig. 5). Therefore, castings that are more developed and structurally complex (sharp edges, perpendicular planes) are more prone to cavitation.

Fig. 5. Areas of remaining castings visually inspected at beginning of mould life and 30% of mould life

By analysing the simulation results, it can be concluded that the tendency to cavitation is directly influenced by the use of vacuum. As the pressure in the cavity decreases, the tendency to cavitation increases. This is due to the existence of suitable conditions for the phenomenon. The initiation of cavitation requires a boiling process caused by a pressure differential in the cavity [12]. Due to the very high speeds used in die casting, even at atmospheric pressure, media can form in the cavity at a significantly reduced pressure. When the cavity pressure is reduced to a value of 200 mbar, the tendency to cavitation is significantly increased and the influence of cavitation media is further increased.

Through the use of simulation, mould design experience and a continuous improvement process, it is possible to compensate for unfavourable phenomena in the mould. This makes it possible to meet the highest quality requirements of demanding customers such as the automotive industry.

4. CONCLUSIONS AND SUMMARY

Problems of premature mould wear can be caused by the adverse effects of cavitation. Castings with more complex designs (with variable directions of metal flow, with sharp edges, kinks and shadows at the gaps) are subject to its adverse effects. The use of a vacuum has a direct effect on increasing the propensity for cavitation to occur and its presence is currently a necessary addition to die casting technology. Recommendations from the research presented in this article suggest that when implementing technologically challenging projects, an analysis of the potential for cavitation problems and their negative impact on the die casting mould should be carried out, for example using the 'cavitation potential' simulation module.

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