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Production of magnesium die castings with hollow structures using gas injection technology in the hot chamber die casting process

M. Becker
Aalen University of Applied Sciences, Aalen, Germany

L. Kallien, T. Weidler
Aalen University of Applied Sciences, Aalen, Germany

ABSTRACT

Magnesium as a lightweight material is very useful to construct innovative lightweight designs in the automotive sector. The disadvantages are the mechanical properties for using magnesium in chassis or car body concepts. The advantages are the good castability in high-pressure die casting with high production rate in hot chamber die casting process and the low densities between 1,71 and 1,83 g/cm³. To compensate the low modulus of elasticity hollow structures can be integrated in structural parts to increase the stiffness. The gas injection process is a possibility to create hollow structures by using a high pressure of nitrogen. The main benefits of this process are creating channels in high-pressure die casting parts and reducing of porosity in thick parts by setting a high gas pressure, a shorter cycle time through a faster cooling rate.

INTRODUCTION

The use of lightweight materials for car body construction and body-in-white (BIW) helps to meet the current environmental demands regarding CO2 emission and fuel consumption. It is necessary to tap the high potential of lightweight design by using especially lightweight materials, such as magnesium. High-Pressure die casting offers the possibility to manufacture structural parts from lightweight materials such as aluminum and magnesium in large quantities and at a moderate price, as high-pressure die casting is one of the most economical casting processes. Moreover, die cast components display high mechanical properties and allow for very thin wall thicknesses. In the automotive sector, especially, car body concepts with the intensive use of castings are being increasingly developed to reduce the overall weight. Aluminum-intensive car body concepts have so far been limited to high-end vehicles, yet they are also moving into other classes of vehicle such as Daimler's new C-Class [Audi 12, BMW 12, Daimler 12, Böhnlein 09]. Aluminum or magnesium castings are increasingly used for car-body construction and BIW as soon as several unformed components can be substituted by a casting. An example of this is the shock tower, Figure 1.

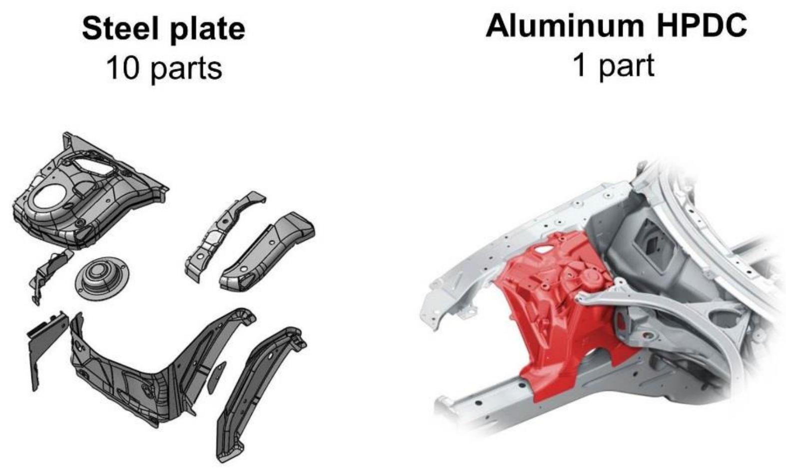

Figure 1: Shock tower made of steel sheet parts substituted by one aluminum die-cast component (Audi 12)

Magnesium constructions would be even more suitable to replace conventional structures made of aluminum and steel sheet, because magnesium alloys, with densities between 1.71 and 1.83g/cm³, are among the lightest of all technical metals. A major disadvantage of magnesium alloys compared to aluminum, however, is their low modulus of elasticity of 45 GPa. The properties of a component, in particular its stiffness, are not only determined by the material but mostly by the design geometry. Thus the low modulus of elasticity of magnesium needs to be compensated by modifications of the geometry in the form of hollow structures to make it suitable for use in the field of structural components. Three-dimensional hollow structures as shown in Figure 2, however, are not feasible in die casting, apart from using salt cores.

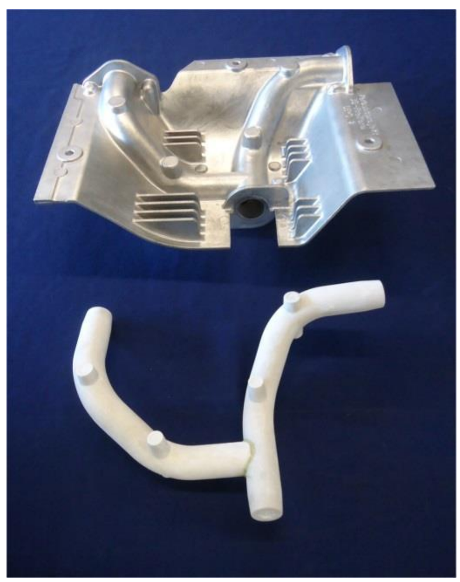

Figure 2: Salt core and die casting with cavity [Kallien, Böhnlein 13]

The gas injection technique is an innovative method for the production of three-dimensional hollow structures originally used in plastics technology [Berthold 04] and so far only used in cold chamber die casting. [Kallien, Weidler, Herrmann 06], [Kallien 12].

THE GAS INJECTION PROCESS

With the gas injection process a cavity is created within the part by a gas entering under high pressure, thereby displacing the still liquid metal in the solidifying part into an overflow cavity. This technology makes it possible to produce cavities in a die casting. Figure 3 shows different geometries already produced with the cold chamber die casting technology from aluminum and magnesium alloys at Aalen University.

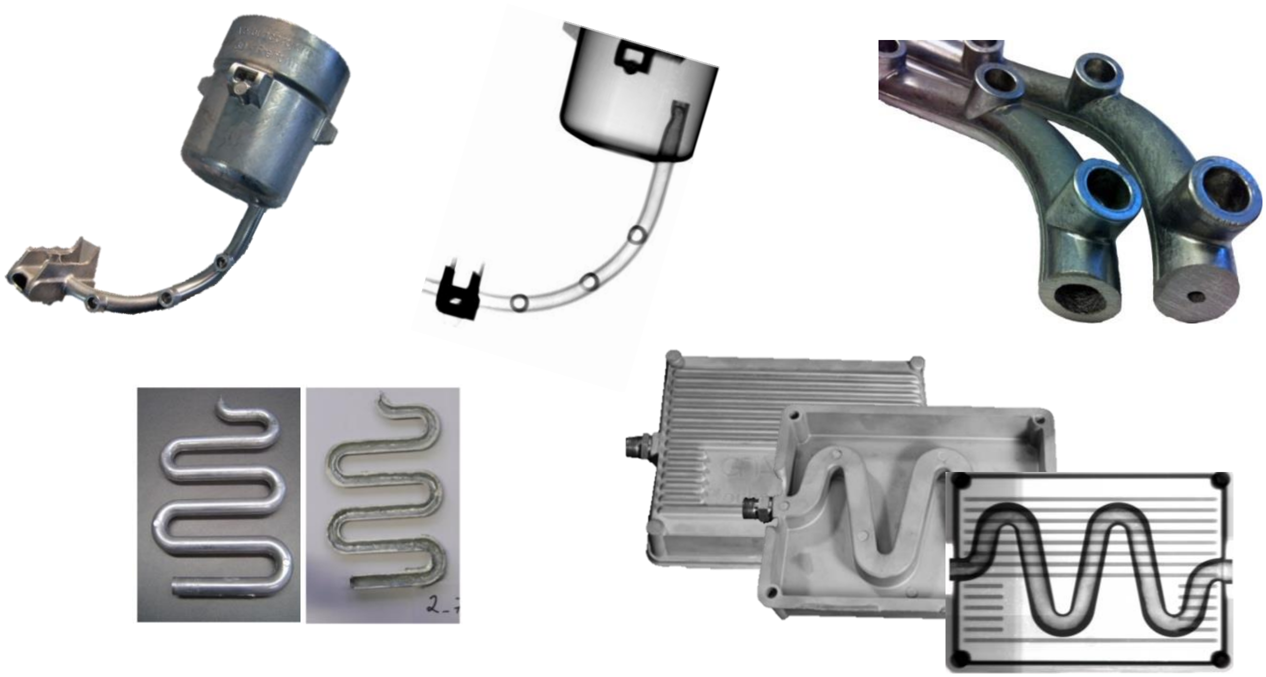

Figure 3: Examples of die castings produced in Aalen by gas injection using the cold chamber casting technology

This publication describes the latest results of the research project "Gas Injection Technology in Magnesium Hot Chamber Die Casting" aimed at applying the gas injection technology to magnesium hot chamber die casting, taking the necessary safety precautions into account, Figure 4. As regards magnesium alloys, the hot chamber process has considerable advantages over cold chamber die casting:

- shorter cycle times
- reduced inert gas consumption
- melting temperature reduced by 40°C
- shorter flow paths
- no premature solidification in the shot chamber
- reduced proportion of returns

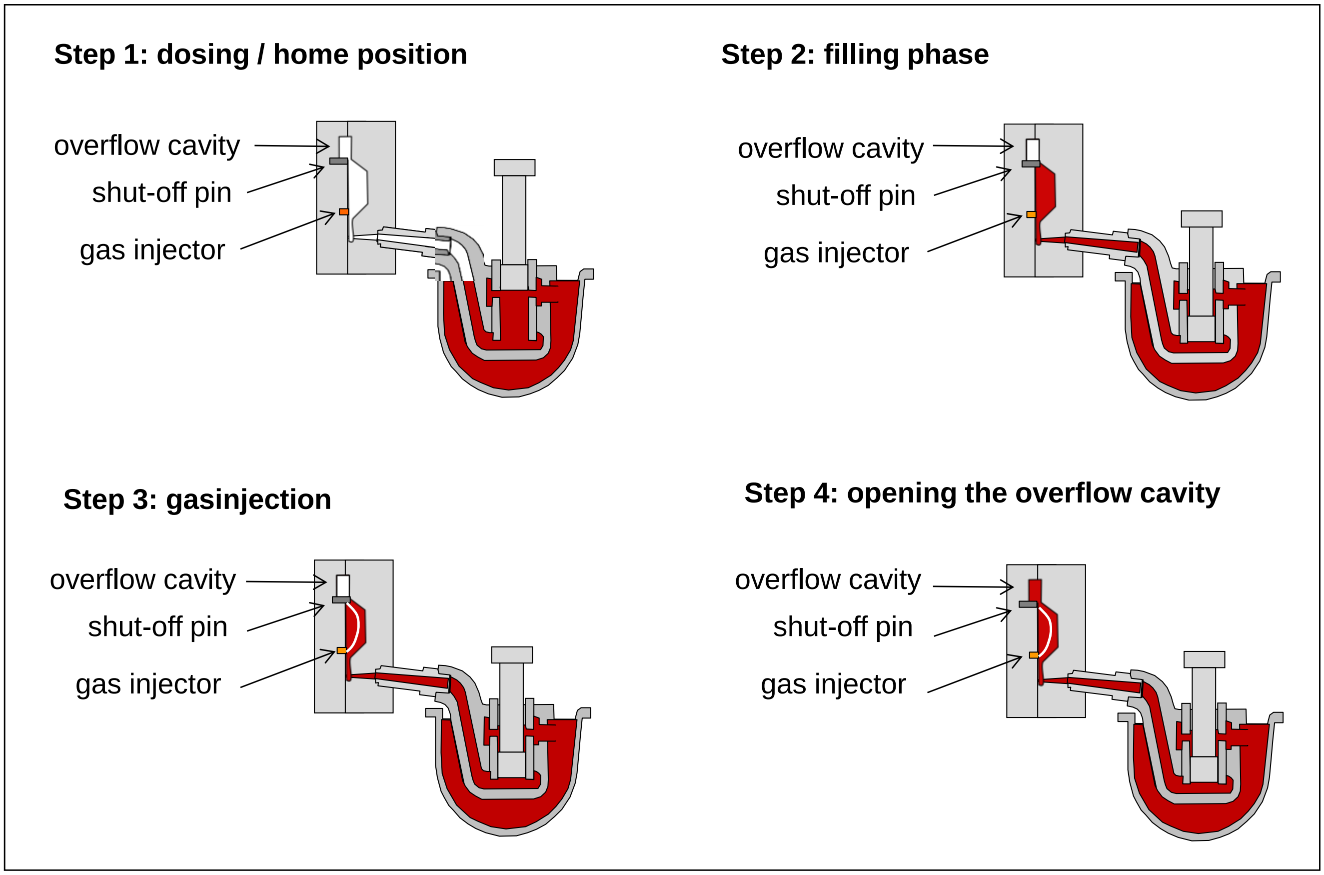

Figure 4: Schematic representation of the gas injection process: At first, the main cavity of the die is filled with molten metal. During die filling, the overflow cavity is separated from the main cavity by a shut-off pin. As soon as gas is introduced under high pressure by the gas injector, the molten metal inside the casting is displaced into the (now open) overflow cavity, and a hollow space is created.

One of the main challenges in this research project was to prevent, under all circumstances, the injection gas from entering the hot chamber machine filled with liquid magnesium alloy through the die via the nozzle and the shot sleeve. This would result in melt leakage, which must be avoided at all events due to the high affinity of magnesium to oxygen.

Therefore, special operating software for the die casting machine and the gas control unit was developed with the project partners Oskar Frech GmbH & Co.KG, Plüderhausen, Germany, and electronics GmbH, Neuhausen, Germany, in order to prevent this from happening. In addition, the gas injection unit had to be further developed to react to extremely short gas injection timings, because magnesium has a much lower heat content than aluminum, and solidification progresses even faster.

In order to present a geometry that is as application-oriented as possible in the framework of the research project, a demonstration part was designed that was inspired by a structural part. This component has a hollow channel to increase stiffness as well as fins on its rear face, Figure 5.

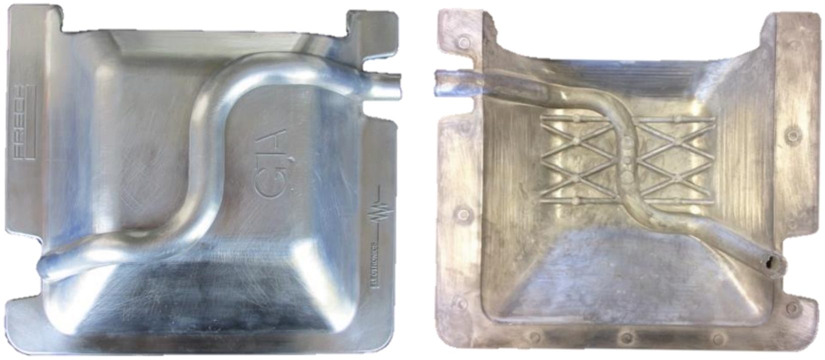

Figure 5: Demonstration part with hollow channel for increased stiffness

The molten metal solidifies in the channel from the periphery towards the center where it forms a liquid and semi-solid state. Due to the rapid formation of a rim zone during die casting, the inflowing gas can be introduced into the liquid channel. Simulation of the solidification process shows the late time of solidification of the channel, Figure 6 [Kallien, Böhnlein 13].

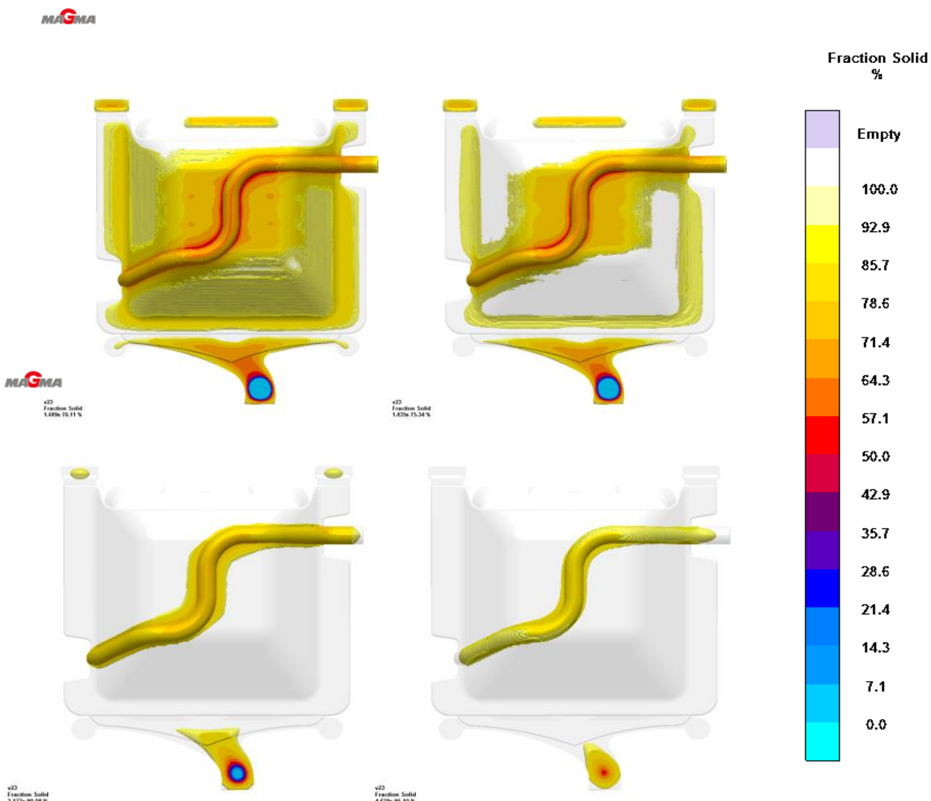

Figure 6: The simulated flow of the remaining melt in the demonstration part illustrates late solidification in a thick-walled channel. The gas injection technology makes use of this effect.

Now the liquid core can be displaced into the open overflow cavity by the gas entering the die cavity. Due to extremely rapid solidification, the requirements of gas injection technology on control engineering are high [Kallien, Weidler, Böhnlein 2009], as the valve switching times have to be reduced to a minimum of a few milliseconds. Furthermore, the gas injector must be able to meet the toughest requirements. During die filling and the holding pressure stage it is critical that no molten metal enter the injector as otherwise it would clog up.

As indicated above, in the hot chamber die casting process the melting furnace is connected to the die casting die via the nozzle. This brings with it the risk that the inflowing gas breaks into the melting furnace. Therefore, the process control of the hot chamber die casting machine was linked to the gas injection plant and its control system to define special safety precautions to prevent, under all circumstances, that gas injection and thus the exit of the gas through the shot assembly into the crucible is triggered in an uncontrolled manner, Figure 7.

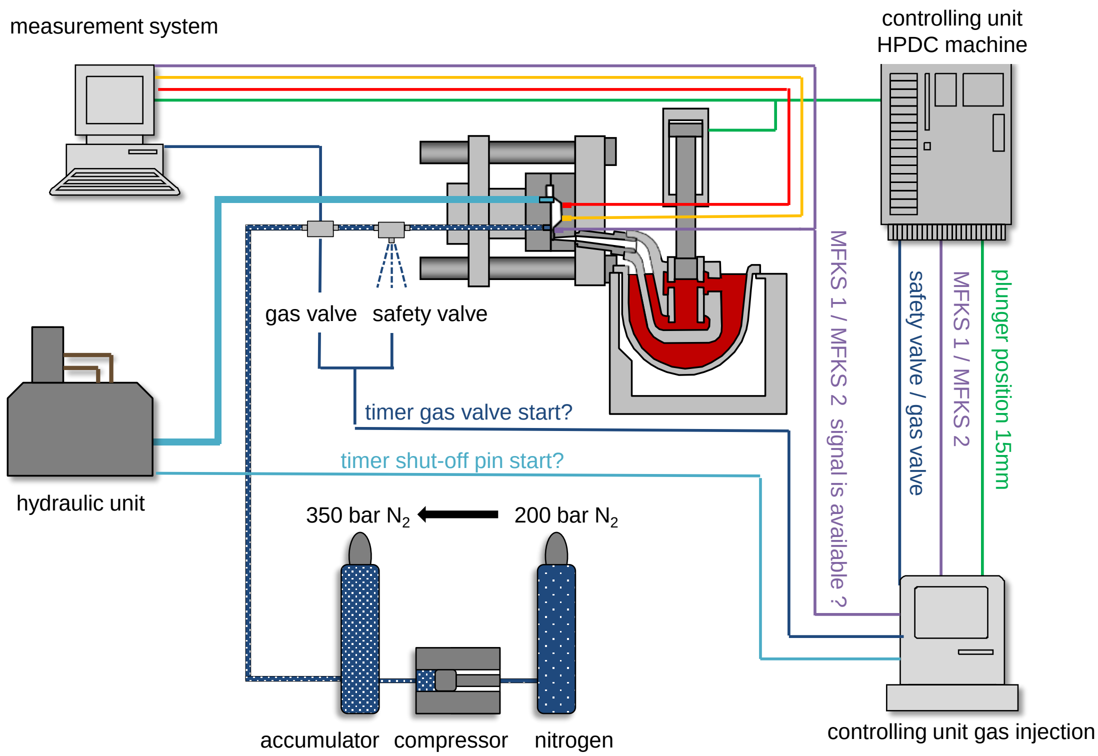

Figure 7: Diagram to show the control-related linking of die casting machine and gas injection unit

The individual process steps of the die casting machine, such as the position of the plunger, are scanned by the gas injection control unit. In order to prevent the exit of the gas into the melting furnace in the event of a malfunction of the gas valve through which nitrogen is introduced into the die casting die, a safety valve was integrated that releases the nitrogen into the atmosphere in case of doubt. The flow of gas into the die is not released by a safety valve until immediately before the actual injection process. The control system of the die casting machine passes information on the position of the safety door, the nozzle, and the die casting die to the gas injection plant, [Becker 13]. With the help of sensors in the die cavity, Figure 8, it was possible to analyze the gas injection process in the shot curve, Figure 9.

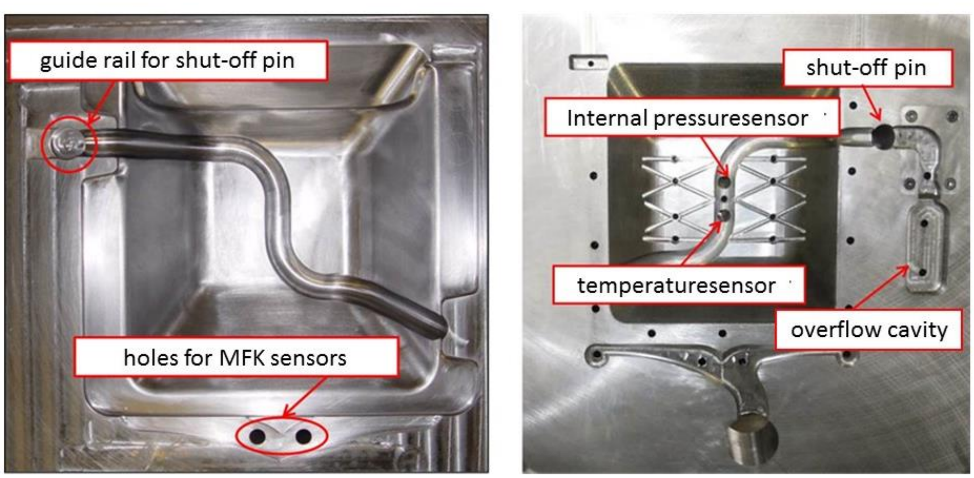

Figure 8: Die casting die with overflow cavity and shut-off pin, drilled holes for the metal front contact sensor and positions for internal pressure and temperature sensors

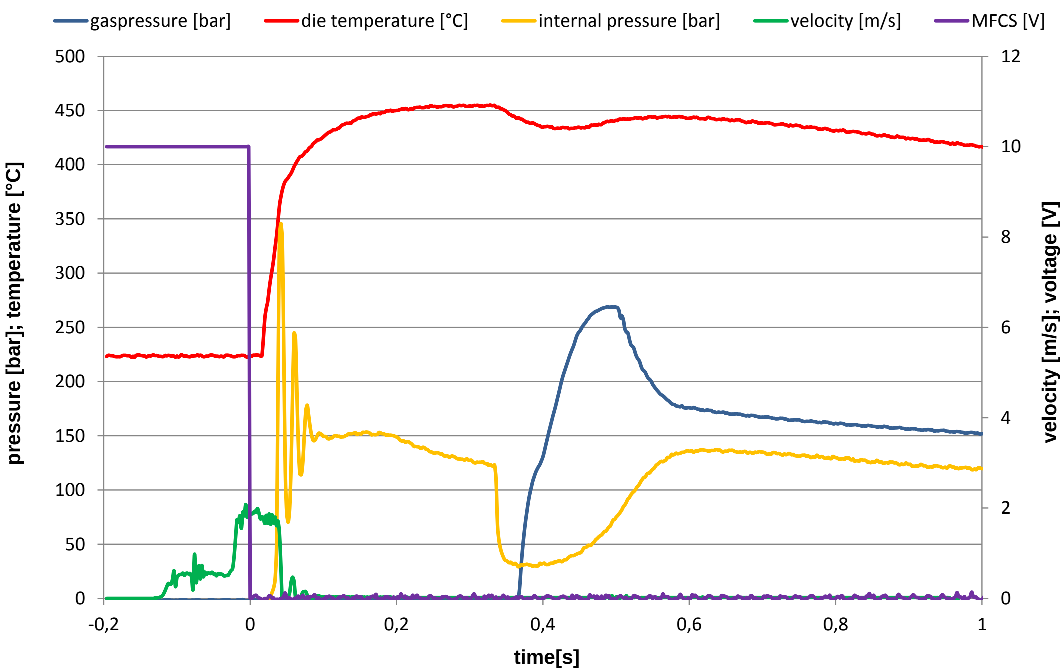

Figure 9: Shot curve recording the gas pressure and cavity pressure in the die

EXPERIMENTAL PROCEDURE

Tests were carried out by varying certain process parameters using statistical Design of Experiment (DoE) methodology. In the process, the moment of gas injection, the release time of the overflow cavity, and the holding pressure time were varied at different stages. The gas injection process was evaluated using 3-D computer tomography.

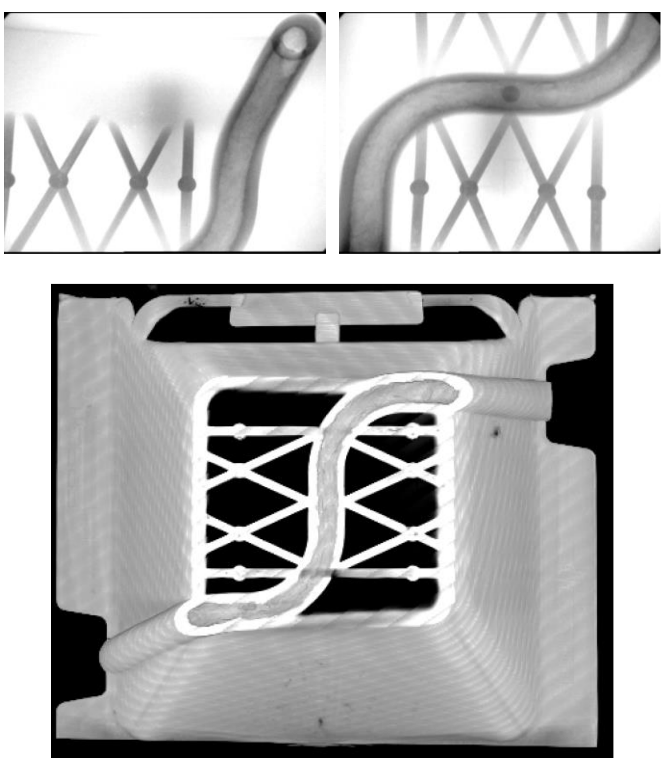

Figure 10: X-ray images (above) and 3-D computer tomography of the gas channel in the demonstrator

To determine the channel volume, the overflow cavity was separated and the channel closed on one side. Subsequently, the channel was completely filled with a liquid. Weight measurements were performed before and after filling to determine the volume. The channel volume was then determined as a function of the release time and the moment of gas injection. Figure 11 shows a clear correlation between the two parameters. The short times indicate that the newly developed control unit has to work in extremely small time intervals in order to generate consistent results. In addition, the valve switching times in the gas injection unit had to be optimized using special coil-speed valve switching accelerators since the short times cannot be achieved with conventional valves.

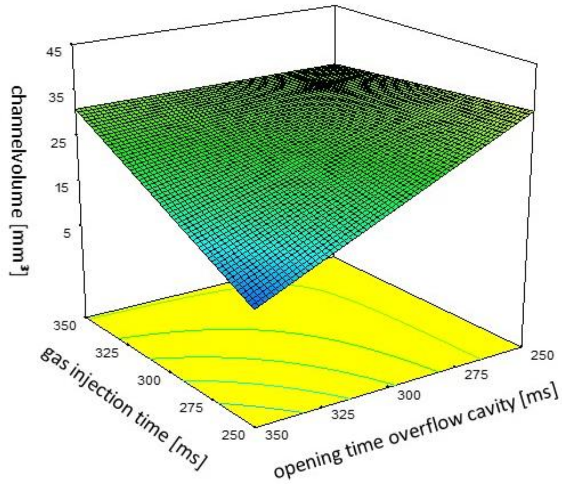

Figure 11: Channel volume as a function of opening time of the overflow cavity and the moment of gas injection

DISUCSSION

The research project was able to demonstrate that gas injection technology can be applied to the magnesium hot chamber process. In the area of the channel the high gas pressure has a positive effect on recompaction of the solidifying magnesium. The demonstrator components were built with scrap rates virtually similar to mass production. In the future, this technology can therefore be taken into consideration for the manufacture of low-cost magnesium die castings with reinforcing hollow channels.

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Contact:

University of Aalen
Gießereitechnologie
M.Sc. Marcel Becker

Beethovenstraße 1
73430 Aalen
Germany

Email: marcel.becker@hs-aalen.de

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