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

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.

Lothar Kallien, **Thomas Weidler** and **Marcel Becker**, Aalen, Germany

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1 Introduction

The use of lightweight materials for car body construction and body-in-white (BIW) helps to meet the current environmental demands regarding CO_2 emission and fuel consumption. It is necessary to tap the high potential of lightweight design by using especially lightweight materials, such as magnesium. 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 pressure die casting is one of the most economical casting processes. Moreover, diecast 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 [1-4].

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).

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 1.83 g/cm^3, 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

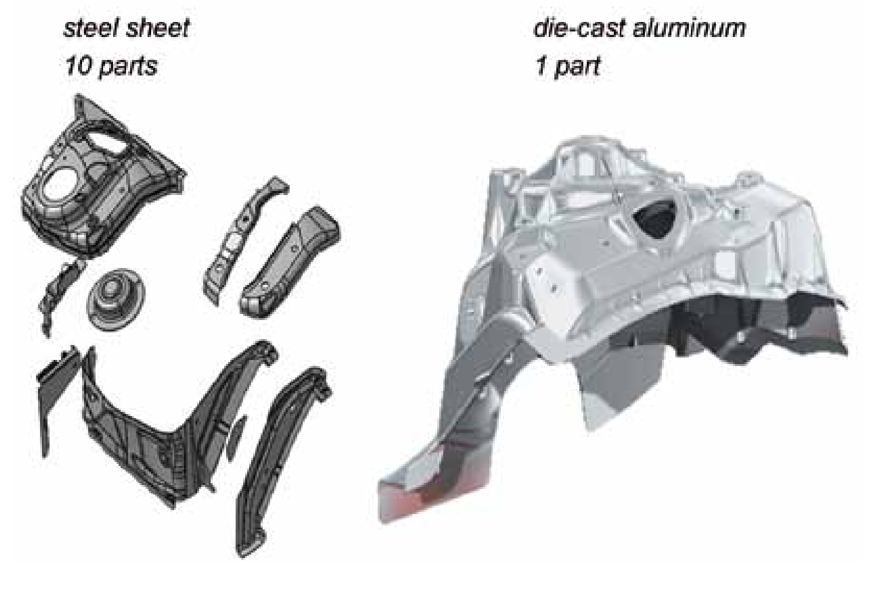


Figure 1: Shock tower made of steel sheet parts substituted by one aluminum die-cast component [1]

magnesium needs to be compensated for 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.

The gas injection technique is an innovative method for the production of three-dimensional hollow structures originally used in plastics technology [6] and so far only used in cold chamber die casting [7, 8].

2 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.

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

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.

Together with the project partners Oskar Frech GmbH & Co. KG, Schorndorf, Germany, and electronics GmbH, Neuhausen, Germany, therefore it has been developed a process-oriented interface, which ensures between die casting machine and gas-injecting unit the required process safety.

In addition, the gas injection unit had to be further developed to react to extremely short gas injection timings,

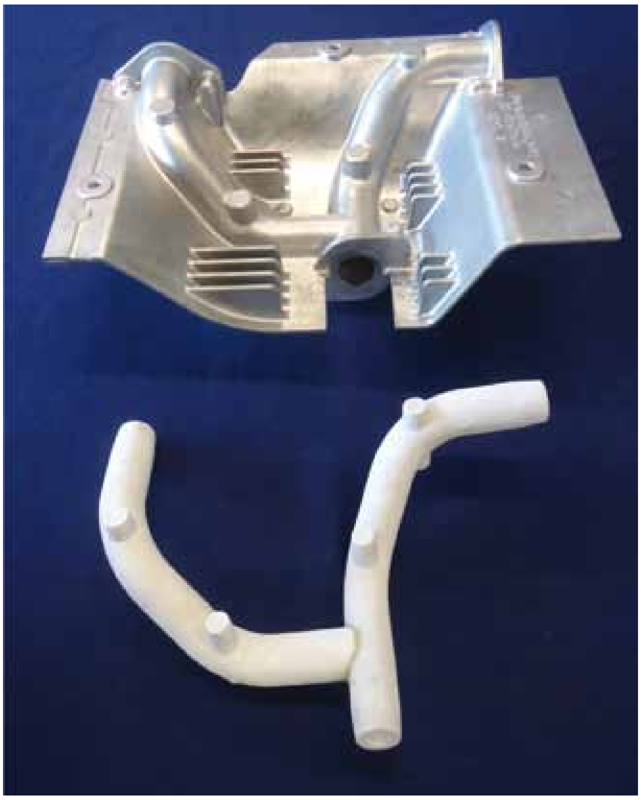


Figure 2: Salt core and die casting with cavity [5]

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

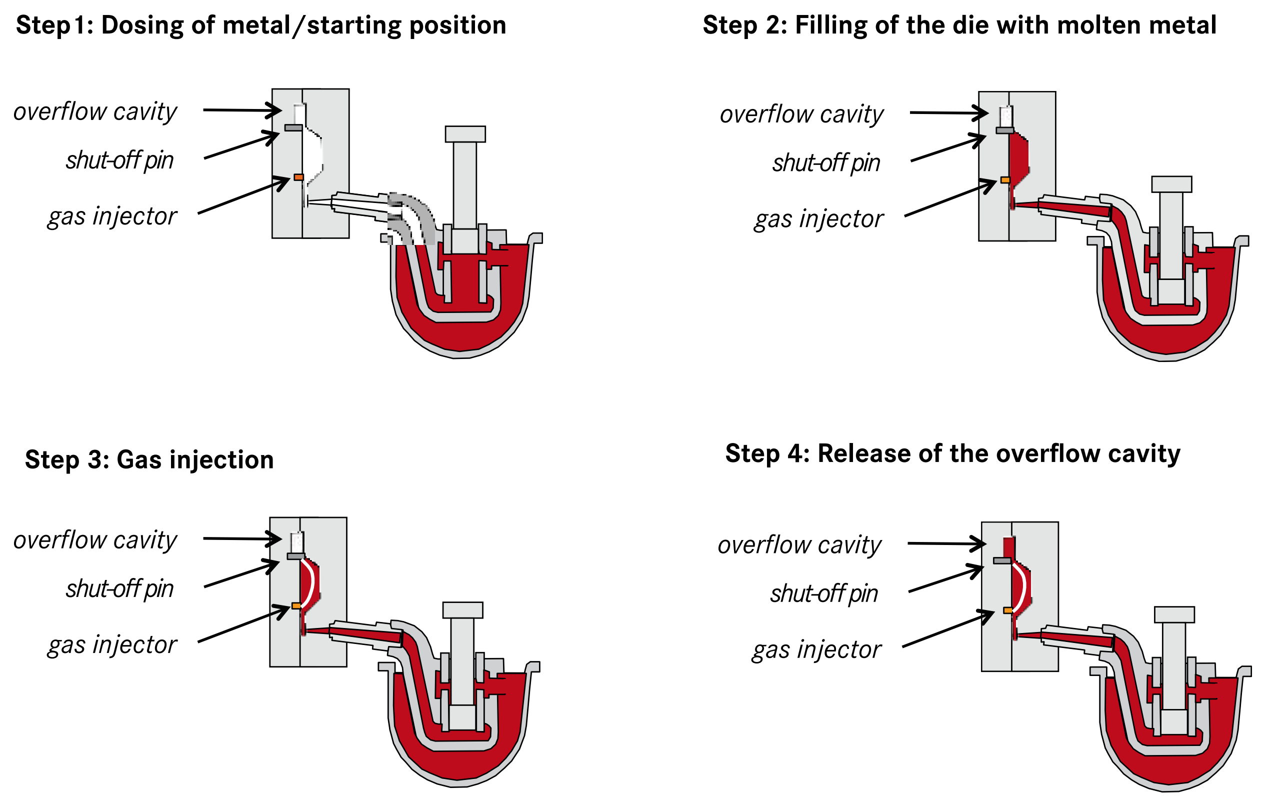


Figure 4: Schematic representation of the gas injection process: At first, the main cavity of the die is filled with molten metal. During die filling, the overflow cavity is separated from the main cavity by a shut-off pin. As soon as gas is introduced under high pressure by the gas injector, the molten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

Figure 5: Demonstration part with hollow channel for increased stiffness

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).

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) [5].

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 [9], 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

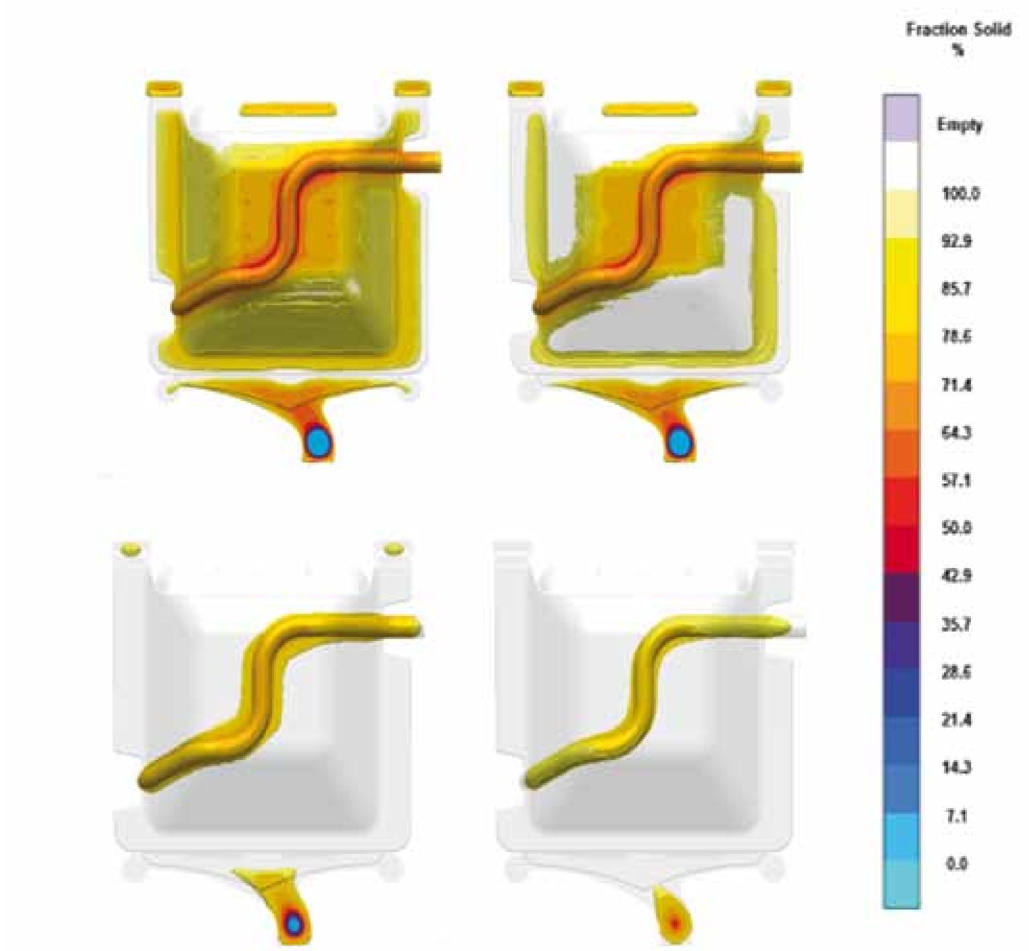


Figure 6: **The simulated flow of the remaining melt in the demonstration part illustrates late solidification in a thick-walled channel. The gas injection technology makes use of this effect**

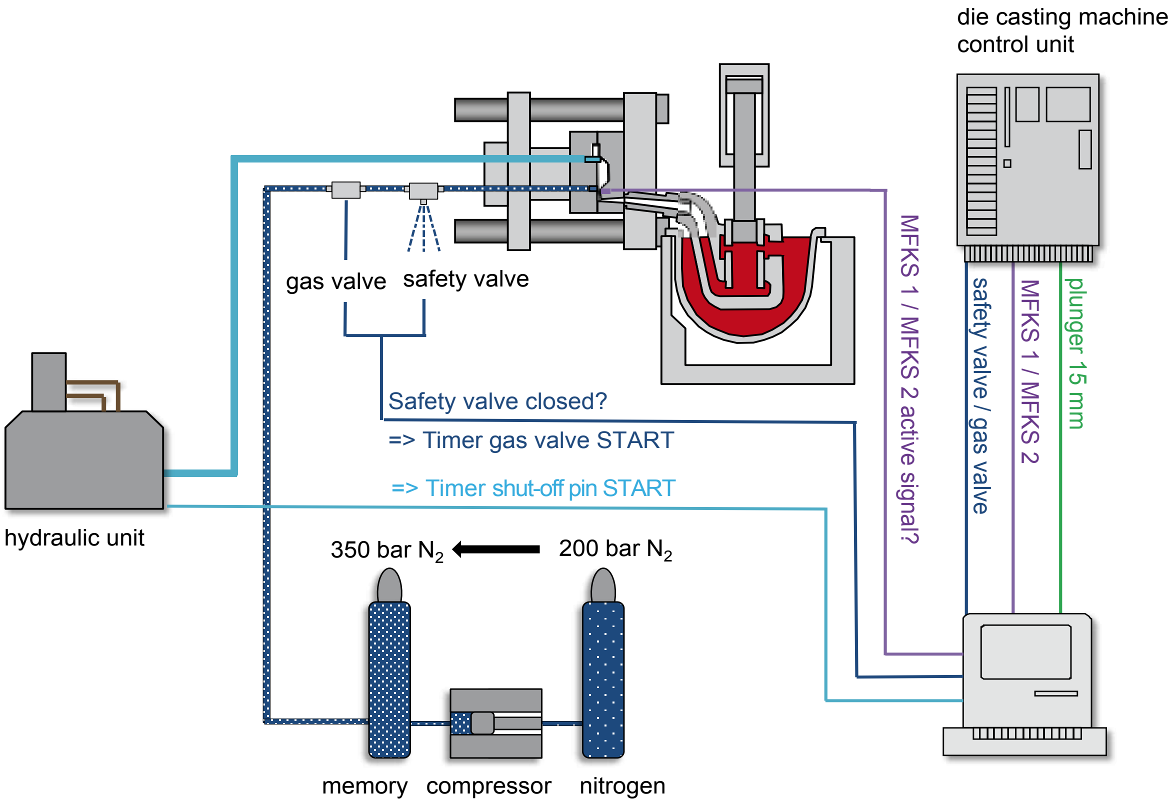


Figure 7: **Diagram to show the control-related linking of die casting machine and gas injection unit**

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 via process-oriented interface 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**).

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 [10]. 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**).

3 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**).

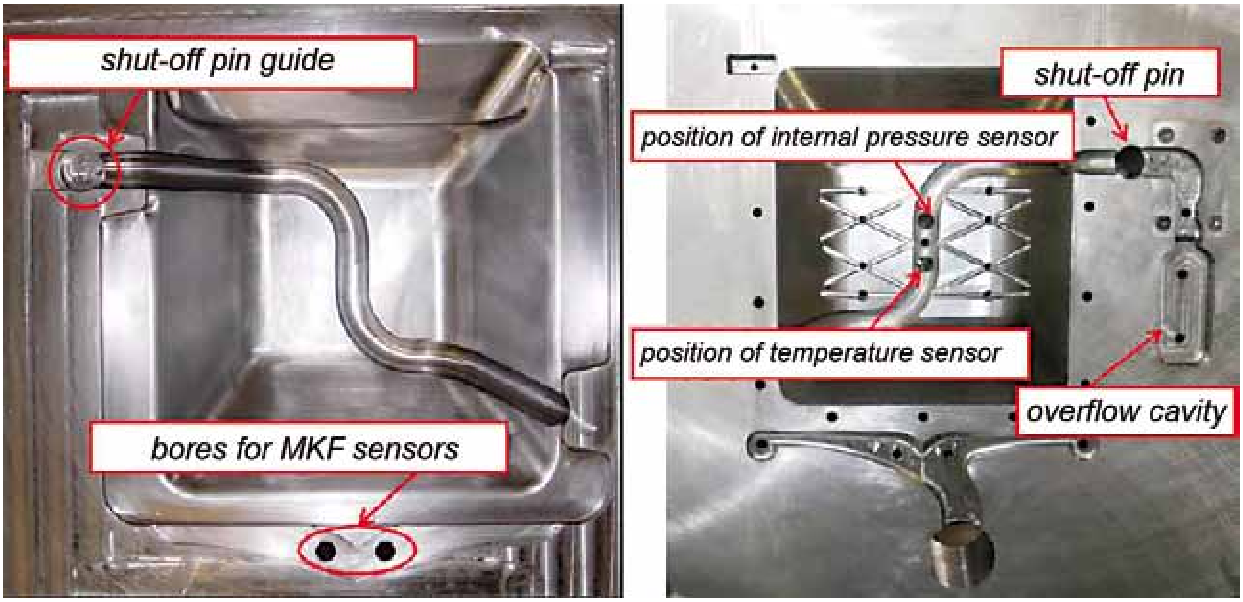


Figure 8: Die casting die with overflow cavity and shut-off pin, drilled holes for the metal front contact sensor and positions for internal pressure and temperature sensors

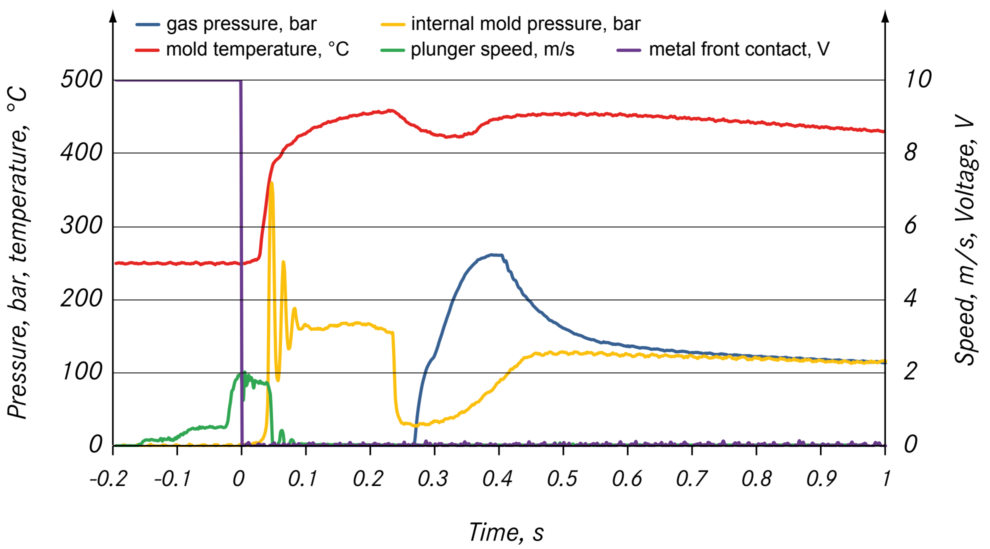


Figure 9: Shot curve recording the gas pressure and cavity pressure in the die

The different parameter settings show different results as regards the porosity analysis in the channel zone. Metallographic examinations were carried out to evaluate the size and quantity of pores.

The extensive solidification porosity in the center of the casting manufactured conventionally and without gas injection can be seen very clearly in Figure 11a. The porosity cannot be compensated by pressure in the third stage. With gas injection (Figure 11b), some pores are still distributed throughout the specimen, but their number could be reduced by optimizing the process parameters (Figure 11c). The local gas pressure in the channel was used effectively for recompaction. With a share of 1.55 percent, porosity was reduced to a minimum. Recompaction by gas pressure highly depends on the parameters of gas injection time and release of the overflow cavity. 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 12 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.

4 Discussion

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.

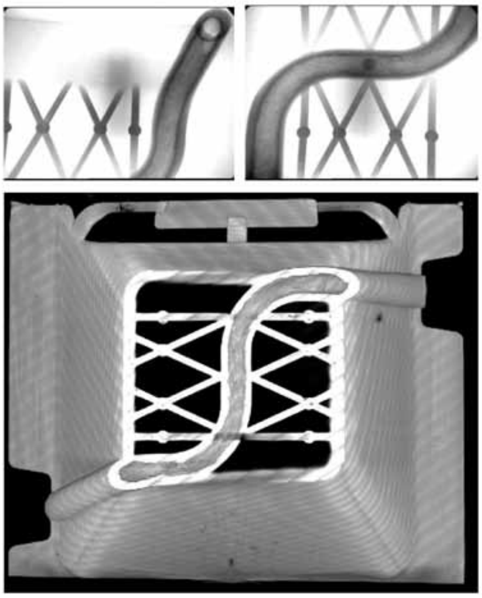


Figure 10: X-ray images (above) and 3-D computer tomography of the gas channel in the demonstrator

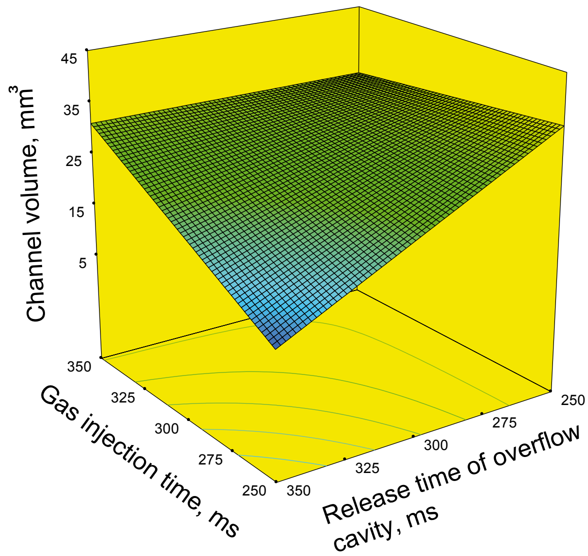
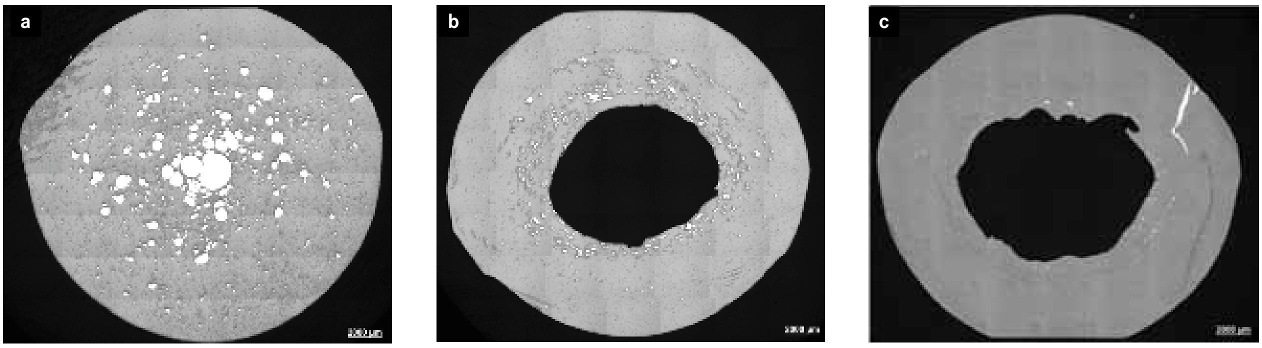


Figure 12: Channel volume as a function of release time of the overflow cavity and the moment of gas injection



average pore diameter, m	13.43
porosity, %	10.6

average pore diameter, m	11.47
porosity, %	3.27

average pore diameter, m	8.3
porosity, %	1.55

Figure 11: Metallographic micrographs of the channel cross section: a) without gas injection, pores and shrink holes can be identified; b) late gas injection, and c) early gas injection

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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***L. Kallien**, **T. Weidler** and **M. Becker**, Aalen University, Foundry Technology, Beethovenstr. 1, 73430 Aalen, Germany*

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