Pressure die castings with functional cavities produced by gas injection

Although first investigations have shown that it is possible in principle to transfer gas injection, which is used in injection moulding of thermoplastics, to the pressure die casting process, this technology is still in its infancy. Additional studies must follow now to further develop this first approach towards a reliable production process.

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A characteristic feature of the pressure die casting process is that it has the shortest process route from the input material to the finished product combined with very short cycle times. It is used whenever high productivity and high production rates are required.

Mould filling does not take place under the influence of gravity as in the case of sand or gravity die casting, but at a high, preset flow velocity in order to counteract rapid cooling of the molten metal in the mould. At the end of mould filling the metal is subjected to a high static pressure in order to compress gas inclusions and compensate shrinkage as far as possible by make-up feeding.

The pressure applied at the end of mould filling allows the still liquid metal to flow into the smallest cross sections and improve the contour quality of the casting. The high flow velocity during mould filling and the subsequent pressurization facilitate above all the production of thin-walled, dimensionally accurate castings with good surface qualities. In this way machining allowances can be dispensed with, resulting in savings in casting material.

The production process is often automated and hence extremely economical. Mainly complex parts used in large numbers, e. g. gearboxes or engine blocks of aluminium, magnesium and zinc alloys, are produced by pressure die casting [1].

There are a number of similarities between injection moulding of reinforced and non-reinforced thermoplastics and the pressure die casting process in terms of the basic process method and the layout of the machine. During the last few years, injection moulding technology has seen the development of many special techniques, such as the gas injection technique. This technique creates cavities in the component by injecting gas (typically nitrogen) at a uniform pressure, enabling economic production of injection-moulded parts of low weight and with defined functional cavities [2, 3].

1 The gas injection process

Figure 1 shows a typical injection moulded plastic part, the cavity of which was produced by gas injection. Plastic parts with such large wall thicknesses would be hardly imaginable without gas injection, because due to the poor thermal conductivity of the plastic material the cycle times would become unacceptably long. Moreover the part would feature considerable sink marks which would be impossible to compensate in the holding pressure phase.

Plastic components with large surface areas are often produced with ribs to enhance their strength and rigidity. On the visible side of the parts these ribs would show heavy sink marks. Therefore these ribs are "blown void" (**Figure 2**). This results in hollow ribs which feature almost the same rigidity as solid ribs, a fact well known from the use of all kinds of hollow sections.

In highly integrated components gas injection also provides the advantage that the warping effect occurring as a result of the solidification behaviour of thermoplastics can be minimized by applying a holding pressure to the remote zones of the liquid material (seen from the gate) to compensate shrinkage.

Recent developments have demonstrated that gas injection is basically also suitable for the production of medium-carrying pipes.

Figure 3 shows further examples of the use of gas injection technology.

The advantages of gas injection can be summarized as follows:

- free design of thin and thick sections;
- localized holding pressure eliminates sink marks and reduces stresses and warpage;
- high stability through hollow sections;
- savings in material;
- reduction of locking force because lower holding force is needed – the internal gas pressure acts uniformly on the component, making part of the holding pressure superfluous.

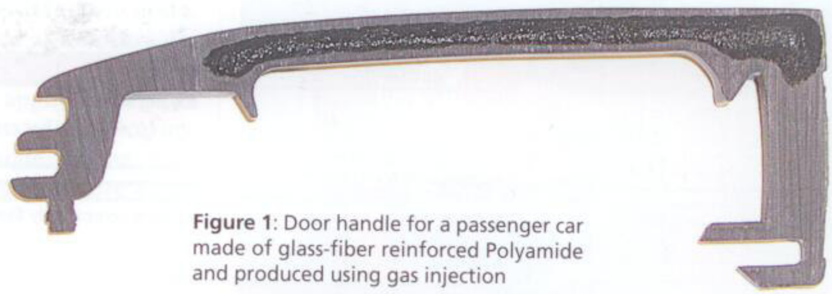

Figure 1: Door handle for a passenger car made of glass-fiber reinforced Polyamide and produced using gas injection

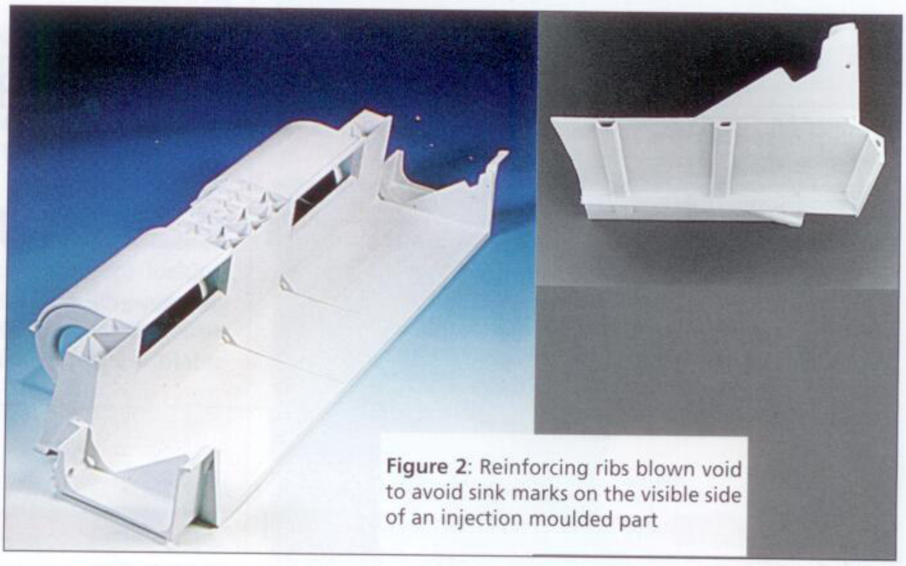

Figure 2: Reinforcing ribs blown void to avoid sink marks on the visible side of an injection moulded part

1.1 Gas injection techniques

This paragraph describes different gas injection techniques [4] in use today.

Gas injection with prefilled cavity. This gas injection process is characterized by the fact that a defined degree of the cavity is prefilled. The degree of prefilling is determined by the geometry of the moulded part and ranges from 50 % in the case of thick-walled parts, such as handles, to about 100 % in the case of components in which the gas injection is only used to compensate shrinkage in mass accumulations [5].

The gas flows into the melt through a feed line near the gate, or sprue. While at the exterior, i. e. at the cold tooling wall, the melt has already solidified, in the center of the part the melt is being displaced by the gas, leading to the complete filling of the cavity. After completion of the mould filling process, also with plastics moulding the gas provides the necessary holding pressure in the cavity. When the melt has solidified, the gas pressure is reduced either by releasing the gas to the environment or by recuperating a certain portion (up to 90 %) of the gas by recirculation (**Figure 4**).

Its numerous advantages have made gas injection with partly filled cavities (**Figure 5a**) the most frequently used technique. As the mould is filled at a low pressure, there is no high pressure peak and hence no risk of mould splashing. This also enables lower locking forces and reduced loading of the mould.

As a result of the pressurization and the smaller wall thicknesses – compared with compact injection moulded parts – cooling and cycle times as well as the risk of sink marks are considerably reduced. Another positive effect is the low pressure level which during the complete process is evenly distributed over the complete part and achieves uniform stress distribution. In compact injection moulding approx. 500 to 800 bar holding pressure must be applied to the freezing and shrinking melt in order to have a pressure level of 50 to 100 bar at the cavity ends to achieve a good surface structure. This often leads to frozen stresses which after removal of the part from mould lead to warpage.

Figure 3: Parts produced by gas injection

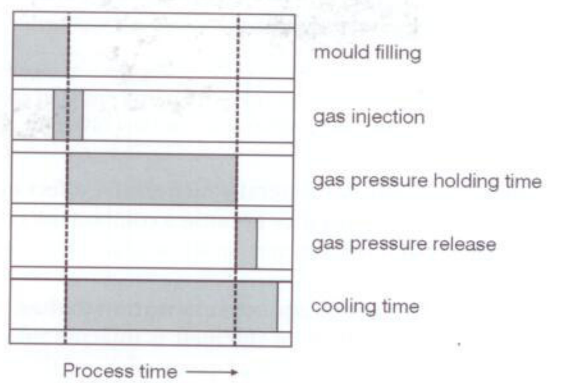

Figure 4: Process steps of gas injection with partly prefilled cavity [4]

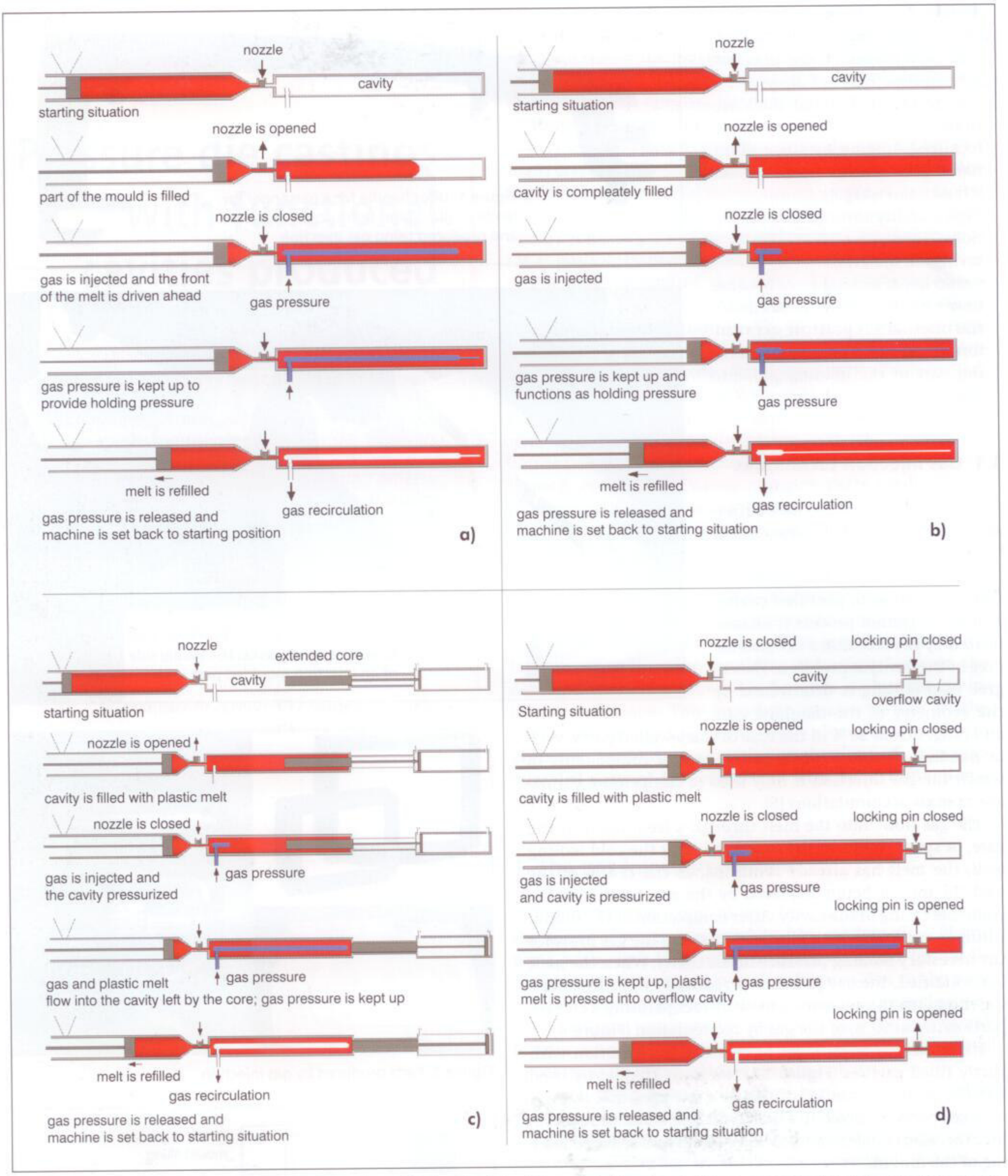

Figure 5: Process steps of gas injection with partly prefilled cavity (a), with gas injection for shrinkage compensation (b), with gas injection and core puller (c), with gas injection and overflow cavity (d)

A cavity in the part has generally no negative effect on its stability and torsion resistance because a component's maximum service load normally acts on its near-surface areas.

Gas injection for shrinkage compensation. When this technique is applied, 100 % of the melt is injected into the mould (Figure 5b). The injection of gas during solidification compensates shrinkage and reduces the risk of sink mark formation on the visible side of the part.

Gas injection with core puller. In this process the melt is injected into a cavity which has been reduced by an inserted core (Figure 5c). After filling the reduced cavity, the core is released and can be pulled out of the cavity. A shell of solidifying melt forms at the cavity wall and at the movable core, while the melt between these shells is still in the liquid state. In this liquid melt area a gas injection pipe is inserted. The gas causes the solidified layers at the movable core and the fixed cavity wall to move away from each other, creating a relatively clearly defined cavity. Only in the level of movement of the movable core does a clearly visible score develop on the surface, which must be classified as a surface defect.

Consequently this technique cannot be applied wherever surface-critical components are to be produced. A typical application of this gas injection technique is the production of beverage crates with hollow grips (**Figure 6**) [6]. Here the score is on the inside.

Gas injection with overflow cavity. Like in the standard injection moulding process the cavity is 100 % filled with the liquid melt (Figure 5d).

The overflow cavity is closed with a gate valve. When the outer shell has solidified, gas is injected through the pipe and the valve of the secondary overflow cavity opened. The still liquid melt flows into the overflow creating a cavity in the moulded part. The system is vented and the moulded part can be removed.

A drawback of this overflow technique is that during the injection process the pressure load on the tooling is as high as in compact injection moulding, i. e. the tool locking forces are no longer lower than with the prefilling process. A higher gas pressure is needed because after the longer retention time in the mould the flow channels still available for the melt are smaller.

1.2 Process parameters

In injection moulding of plastics the typical time elapsing until a sufficiently solid surface shell has formed is about 10 s, because the thermal conductivity of plastic melts is much smaller than that of metals.

Typical process parameters applicable in gas injection processes are:

- gas injection time: 0.1 s;
- hold-up time: up to 10 s;
- gas pressure: 20 to 50 bar; maximum gas pressure: 200 bar

The gas pressure is regulated during the process. Due to the high viscosities a higher pressure is needed to open up the cavity in the melt at the beginning of the process than later on during gas cavity growth.

1.3 Gas injectors

The gas injectors control the feeding of the melt-displacing medium into the cavity. They can have different designs. Some designs feature a movable piston which in a self-cleaning operation removes entering plastic material. The gas injectors are subjected to heavy thermal and mechanical loads when the liquid melt is injected. Gas injectors used in injection moulding of plastic parts are made of steel (**Figure 7**).

1.4 Channel design

In injection moulding of plastics it is possible to influence the shape of the produced channel by changing the outer geometry of the channel to be blown void (**Figure 8**).

Figure 6: Beverage crates produced with the core puller technique

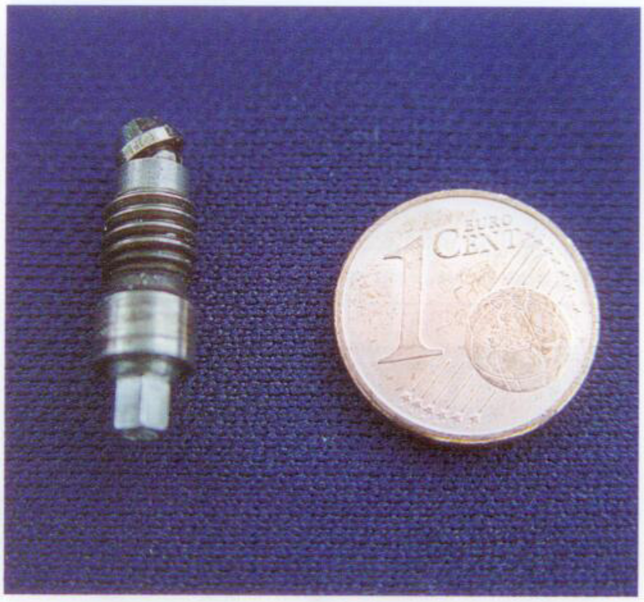

Figure 7: Gas injector

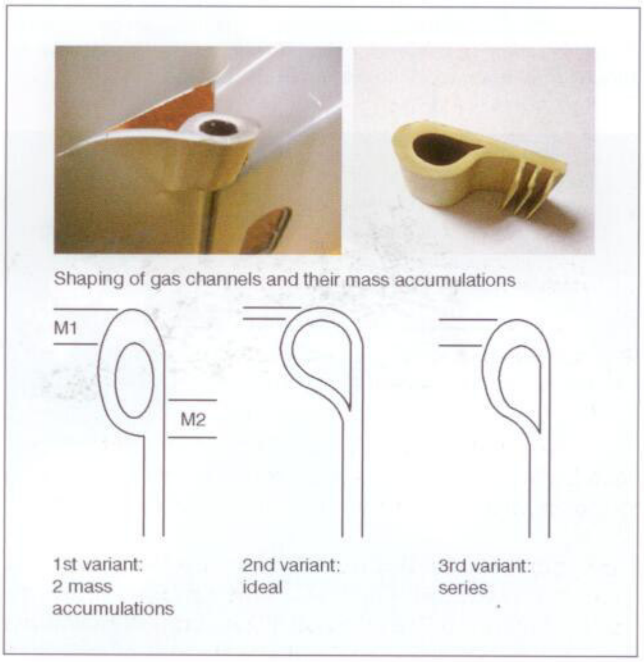

Figure 8: Gas channel shapes and mass accumulations M [2]

2 Use of gas injection in pressure die casting

2.1 Motivation

It would be wise both in terms of technology and economy to use gas injection also in pressure die casting of metallic melts. The production of extremely low-weight parts and the development of innovative pressure die cast constructions including media-carrying pipes that can be produced without costly loose pieces or steel cores would open up new potentials in all application fields of pressure die casting.

Feasible applications could be low-weight pressure die cast door handles made of zinc, media-carrying pipes for fuel supply systems like common-rail injection pipes or void-blown channels in aluminium and magnesium pressure die cast oil filter housings (**Figure 9**). The advantages of these applications include reduced material losses, high pressure-tightness of the castings and cost-efficient large-series production.

Figure 10 shows a complex pressure die casting featuring very long oil bores which have to meet most exacting tightness requirements. Both the precasting of the bores by means of very long cores and the machining of these extremely long bores confront the manufacturing engineer with a series of difficulties. If it was possible to use the gas injection technology to solve these problems, this would certainly open up new potentials for the pressure die casting process.

The problems associated with the use of gas injection in pressure die casting are multiple, ranging from premature solidification of the melt – i. e. gas penetration is insufficient – via irregularly formed gas cavities through to gas break-out. The process is highly unstable with great variations between the individual cycles. The short service life of the existing gas injectors calls for completely new developments in this area.

2.2 Problem discussion

The objective of the first investigations was to transfer the gas injection process used in plastics moulding to pressure die casting of metals with the aim in mind to produce lower-weight components and components with functional cavities. In injection moulding of plastic parts gas injection is state of the art. Nevertheless the application of this technology in pressure die casting still leaves many problems unsolved: When a plastic melt (Polyamide 66) is injected its temperature is between 300 and 320 °C. In this temperature range it is possible to use gas injectors made of steel, which even after an extended period of service do not show any wear. The temperatures of metallic melts, however, reach 420 °C in the case of zinc alloys and up to 700 °C in the case

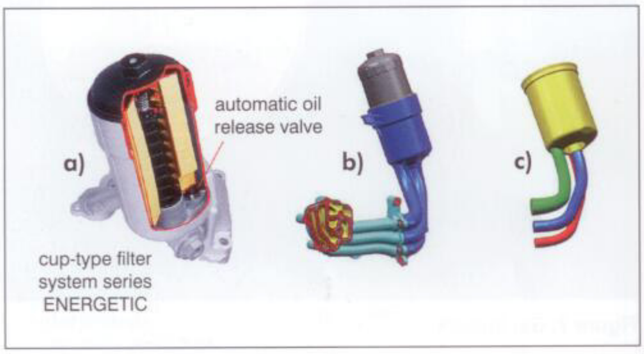

Figure 9: Potential further development of pressure die cast oil filter housings – streamlined 3-dimensional channels can be produced by gas injection: a) conventional oil filter housing, b) potential future oil filter housing, c) illustration of the cavities in b)

Figure 10: A pressure die casting with long bores

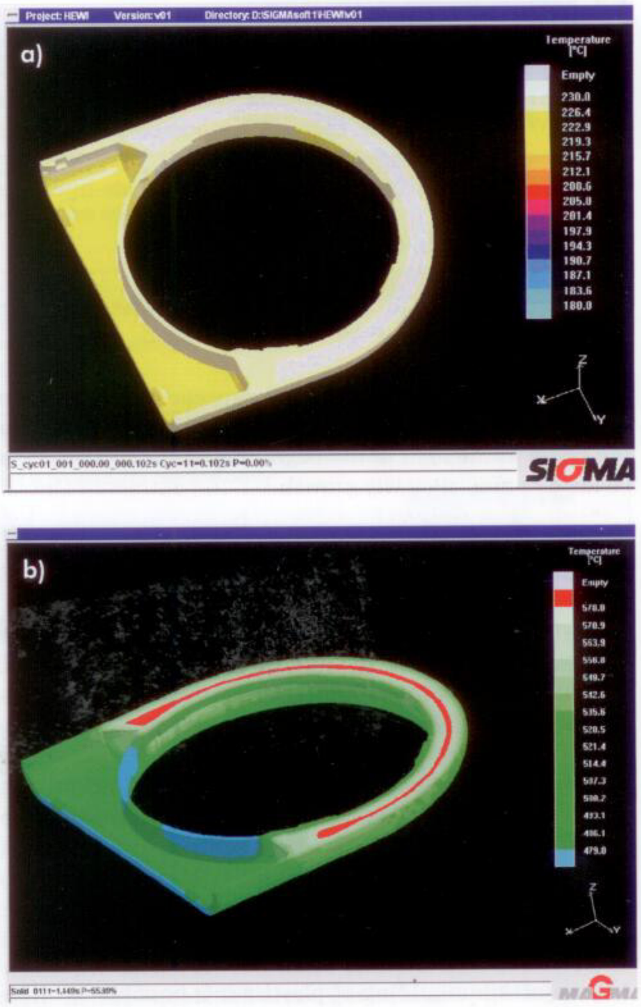

Figure 11: Simulation of the solidification of a plastic component (a) and of an aluminium die casting (b, liquid zones are shown in red)

of aluminium and magnesium alloys. What aggravates the situation is the fact that aluminium melts solve iron. Therefore the development of injectors withstanding uninterrupted service in a pressure casting die, also using aluminium melts, is a big challenge.

Due to the low thermal conductivity of plastics, the gas injection process can take place rather slowly here. As mentioned above, from the injection of the plastic melt until the injection of the gas typically several seconds elapse.

The simulation brings to the light the differences between the use of gas injection in plastics and metals processing (**Figure 11**). The simulation of the plastic moulding process shows that the period available until the no-flow temperature, i. e. the temperature at which the material cannot flow anymore, is reached is distinctly longer than 11 s (Figure 11a). Compared to this, the simulation with a metal melt shows that here the time is clearly below 2 s (Figure 11b). Due to the high thermal conductivity, the liquid zones to be blown void have almost completely solidified already after 1.5 s. Process control must therefore be much faster and more accurate.

2.3 Tooling for pressure die casting with gas injection

The design of the first tooling was based on experience from toolmaking for injection moulding plants. The production of a component that is already produced in series by injection moulding was taken as a model, namely the door handle for a passenger car shown in Figure 1. This part is made of fibre-glass reinforced Polyamide 66 and features a cavity formed by gas injection.

Figure 12 shows the layout of the pressure die casting tool for a 200 t cold chamber pressure die casting machine. The overflow cavity, which can be opened and closed by a locking pin, is clearly visible.

2.4 Investigations on the production of functional pressure die castings using gas injection

In order to obtain a basic understanding of the necessary process parameters, as a first step pressure die castings made of a zinc alloy were produced. In contrast to zinc alloys, aluminium alloys have the advantage that the thermal load on the gas injectors is smaller. The first tests were conducted with a conventional gas injection plant of Stieler Kunststoff Service GmbH, Goslar, Germany, on a 200 t cold chamber pressure die casting plant.

Initially a central sprue was used (runner 1, see Figure 12) in order to avoid direct contact between the gas injector and the molten metal. As this position soon proved to be unsuitable, the sprue system was modified (runner 2, Figure 12) (**Figure 13**). The reason for this modification becomes obvious in the mould filling simulation for both variants (**Figure 14**). In the version with the central sprue (Figure 14a) the zone opposite to the gas injector is filled first and then quickly cools down. When the gas is being injected, this part of the melt has already solidified, making it impossible for the gas cavity to penetrate the solidifying casting completely (**Figure 15**a). In the optimized variant with a bottom sprue (Figure 14b), on the other hand, the top is the last part of the cavity to be filled.

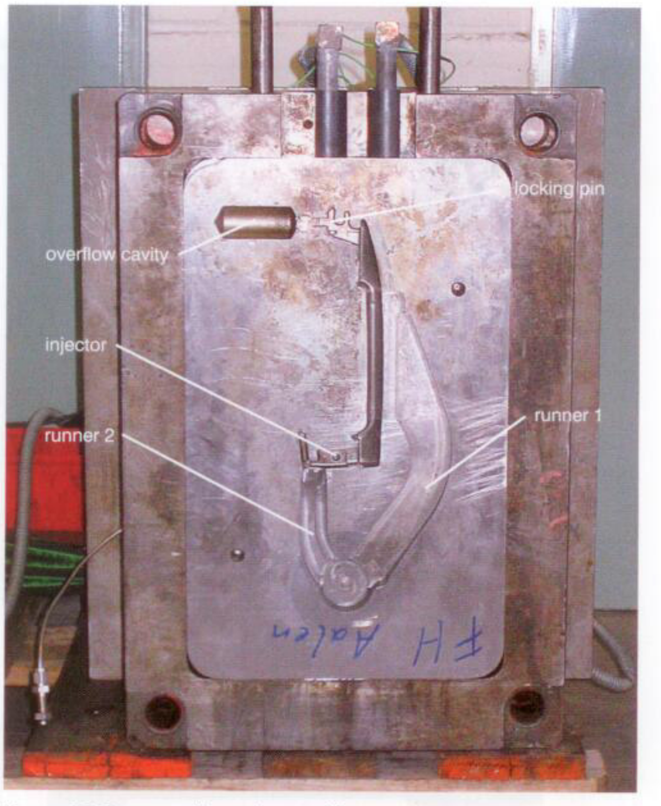

Figure 12: Pressure die casting tool for gas injection and a 200 t cold chamber casting machine

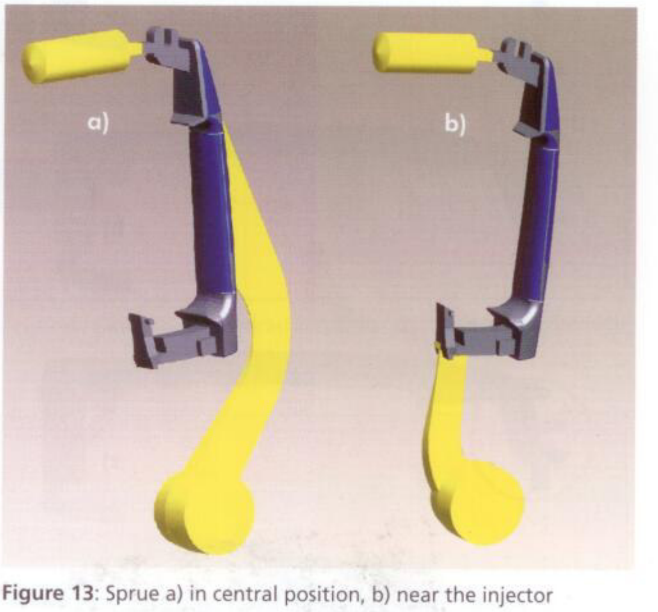

Figure 13: Sprue a) in central position, b) near the injector

Figures 15b and c show defective castings from the first tests: If gas injection starts too late (Figure 15b), the melt has already solidified and the gas cavity cannot penetrate the casting. The same problem occurs when the die temperature is not high enough (Figure 15c) [7].

After numerous preliminary tests, the first pressure die cast part moulded by gas injection could be successfully produced with a zinc alloy (**Figure 16**). A salient feature is the smooth surface of the cavity which reminds of the surface structure of blow holes in castings. Also there the metal solidifies under high pressure. This is an effect that should certainly be kept in mind for developments in connection with the production of media-carrying pipes. Near the gas

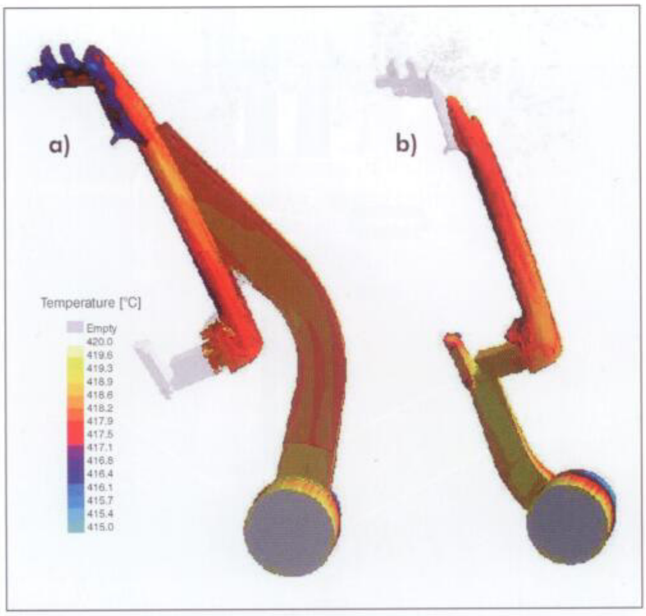

Figure 14: Mould filling simulation with 90 % filling: a) sprue in central position, b) optimized sprue near the injector

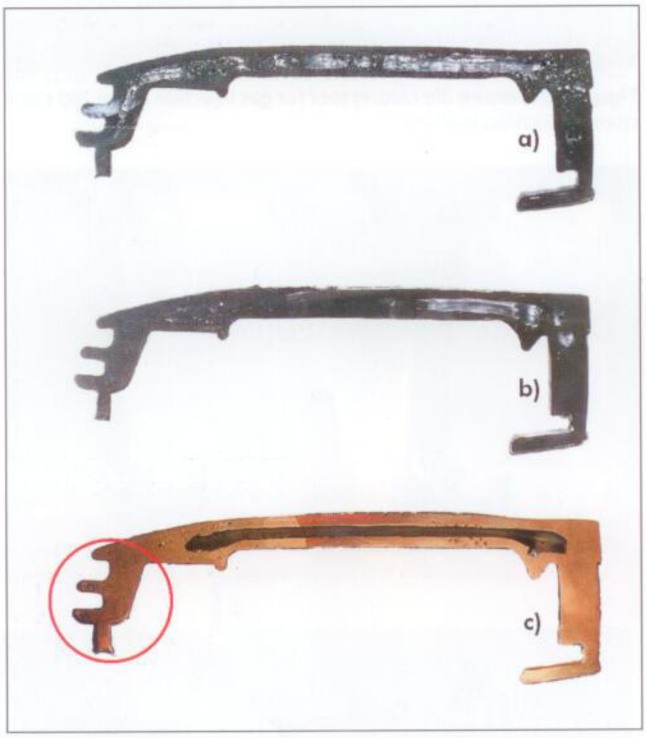

Figure 15: Possible causes of failure occuring during pressure die casting with gas injection: a) gas injection and central sprue; b) delayed gas injection; c) die temperature too low

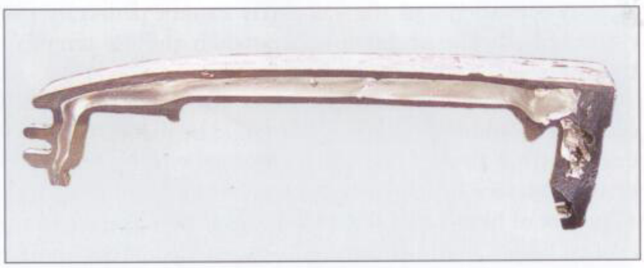

Figure 16: Zinc pressure die casting with cavity completely produced by gas injection

injector (right part of the casting shown in Figure 16) all castings featured a foamed zone which obviously is the result of turbulences occurring during gas injection. As this zone is limited to the beginning of the gas injection process, an imaginable solution could be to position the gas injector outside the cavity proper.

After the successful production of zinc alloy pressure die castings, subsequent tests were geared towards pressure die casting of magnesium. It quickly turned out that the controls of conventional gas injection plants are too slow for the production of pressure die castings made of metals. This applies to both the pressurization of the displacement gas and the pressurization for the actuation of the locking pin of the overflow cavity. Consequently a new plant was designed and installed capable of controlling the gas injection valve and the hydraulics of the overflow cavity (**Figure 17**). The controls for the gas injection and the hydraulic cylinder are coupled with the pressure die casting machine. **Figure 18** shows a magnesium alloy pressure die casting with a cavity produced by means of the new gas injection plant.

3 Summary and outlook

First activities have shown that it is possible in principle to transfer the technology of gas injection to the pressure die casting process. This development is, however, still in its infancy. Much of research is still required in many areas to further develop this initial approach into a reliable production process. One precondition is a fast-acting gas flow control because metals solidify much faster than plastics due to their much higher heat conduction capacity. The call for a fast and accurate gas flow regulation is combined with the requirement of maximized precision of dosing. The gas injectors are susceptible to clogging if the gas supply is delayed. Moreover, near the gas injector the cast metal tends to foaming. Gas injectors made of steel are unsuitable for casting aluminium alloys because they are chemically attacked by the aluminium melt. Therefore new ceramic materials must be developed for this application. The process results generally spread within a wide bandwidth. However, due to the small number of castings produced in the tests no statement can be made about the feasibility of series production. Nevertheless the obtained results are so promising and convincing that the study will be continued within the framework of research projects scheduled for the near future.

Literature

[1] Brunhuber, E.: Moderne Druckgussfertigung. Fachverlag Schiele & Schön 1971.
[2] Michaeli, W.; Brinkmann, T.; Gessenisch-Henleys, V.: Kunststoffbauteile werkstoffgerecht konstruieren. Carl Hanser Verlag 1995.
[3] Menges, G.; Mohren, P.: Spritzgießwerkzeuge. Carl Hanser Verlag 1991.
[4] Eyerer, P.; Elsner, P.; Knoblauch-Xander, M., e. a.: Gasinjektionstechnik. Carl Hanser Verlag 2003.
[5] Märtins, R.; Diener, L.: Gasinnendrucktechnik. Stuttgarter Kunststoff-Kolloquium, Konferenz-Einzelbericht 14, IKP 1995.
[6] Dworog, A.: Hengst Filterwerke 2006.
[7] Kallien, L.: Herstellung von Druckgussteilen mit funktionalen Hohlräumen durch Gasinjektion. Vortrag, Große Gießereitechnische Tagung, 21. und 22. April 2005, Innsbruck. Verein Deutscher Giessereifachleute und Verein Österreichischen Gießereifachleute 2005.

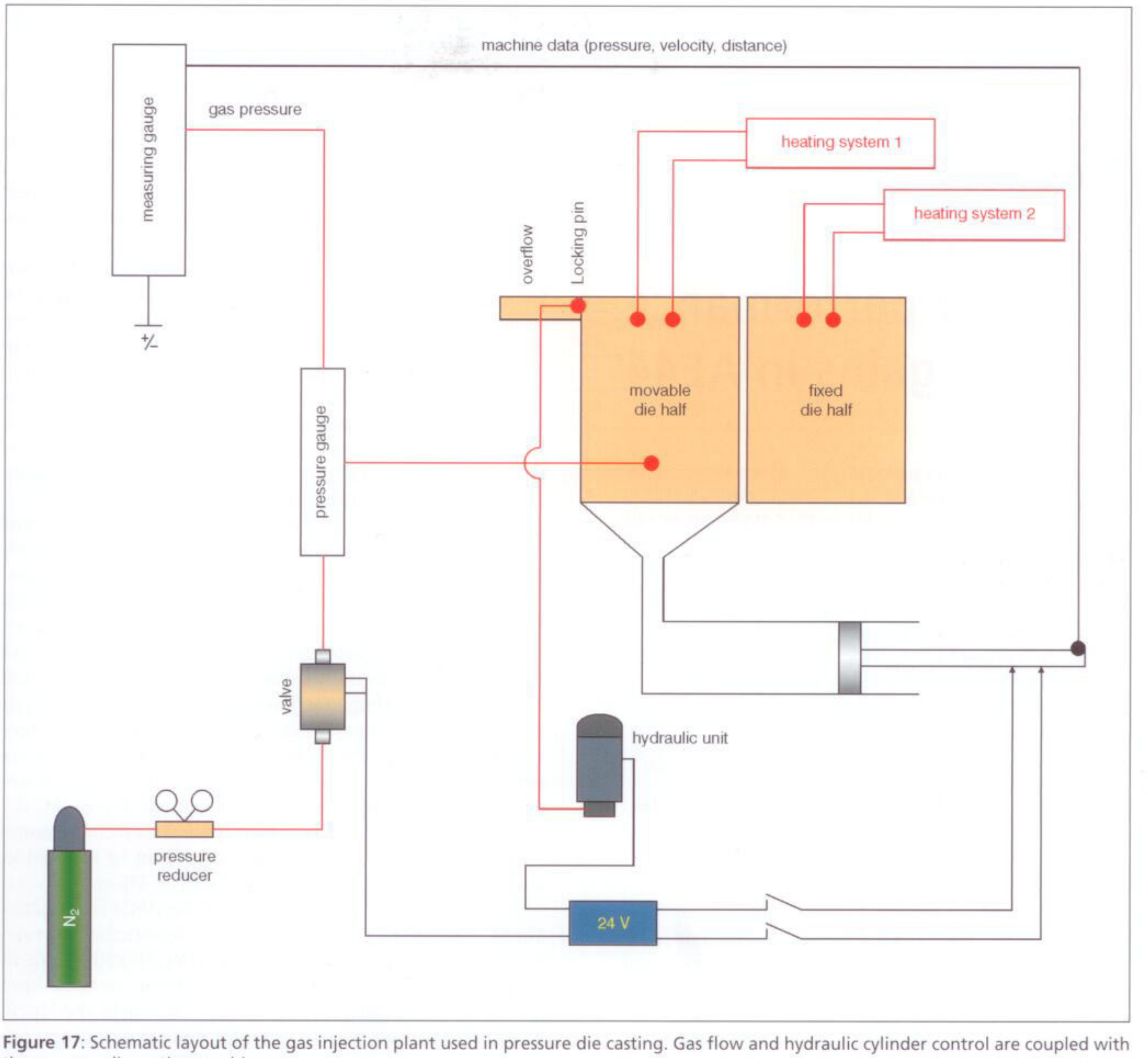

Figure 17: Schematic layout of the gas injection plant used in pressure die casting. Gas flow and hydraulic cylinder control are coupled with the pressure die casting machine.

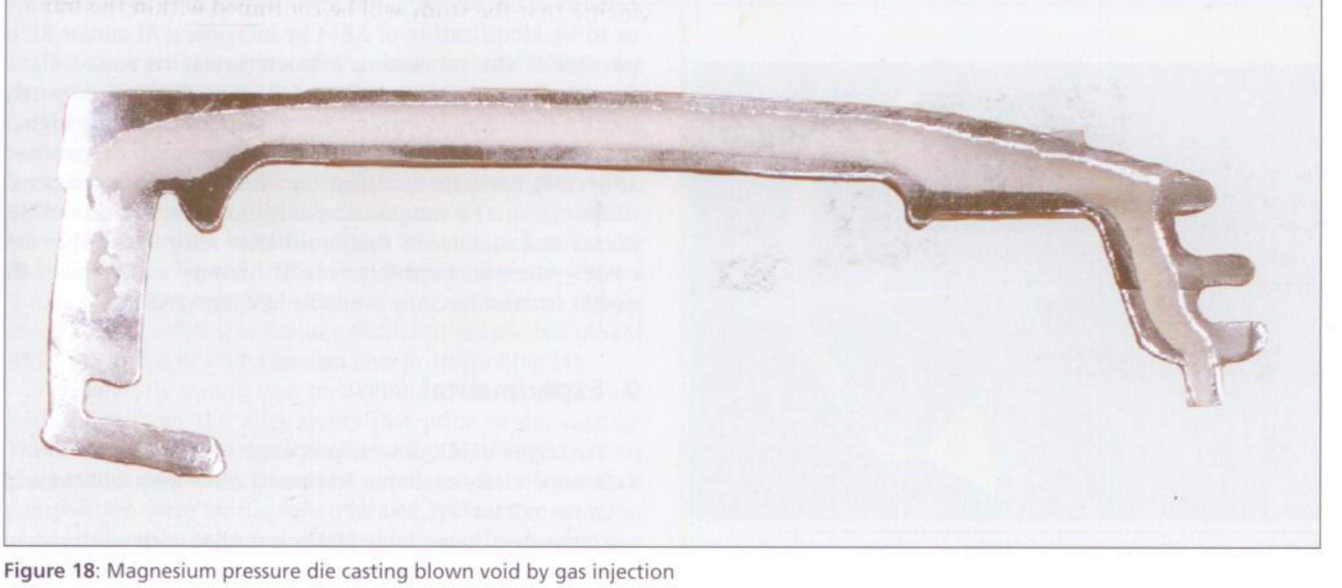

Figure 18: Magnesium pressure die casting blown void by gas injection