



# Gas content in high pressure die castings

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## ABSTRACT

This paper presents the results of a quantitative study of the gas level in various types of castings from the high pressure die casting (HPDC) process using a vacuum fusion method. It was found that the major part of the gas was from the air entrapment during cavity filling. Other sources such as air entrapment during ladling, residual die lubricant and quenching water were also noticeable. Measurements of a large casting and castings from a multi-cavity die showed that the gas content was unevenly distributed. The modified vacuum fusion method has been proved to be a valuable tool for evaluating and quantifying the level of gas in castings as well as for an assessment of the influence of different process parameters on gas evolution in castings.

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## 1. Introduction

High pressure die casting (HPDC) is a cost-effective process widely used to produce components with high productivity and high dimensional accuracy for automotive and other industries. A disadvantage of this process is the gas entrapment due to the highly turbulent flow of metal in the cavity. The entrapped gas remains in the casting in the form of gas porosity which hinders the casting's suitability for conventional heat treatment and deteriorates the casting quality sometimes to such a degree that it must be rejected.

In the cold-chamber HPDC process, air can be entrapped during the metal pouring, plunger advance, and metal injection. Lindsay and Wallace (1972) reported that the fill ratio of the metal in the shot sleeve has a significant influence on the gas entrapment. This is caused by the wave formation and propagation during the plunger advance as demonstrated with a simulation by Wang et al. (2003). In this case of half-filled shot sleeve, the air in the shot sleeve plus the air in the cavity is approximately three times of the volume of the metal poured into the shot sleeve. Clearly it could be a significant source of gas.

Oil is used in the process to lubricate the plunger tip in the shot sleeve, and other forms of die lubricant are used to assist in the casting removal from the dies. These lubricants can evaporate or burn once in contact with the molten metal. Lindsay and Wallace (1972) reported that lubricant evaporation did not play an important role in the porosity generation. It is envisaged that their conclusion was based on a casting having a simple shape used in the study. With a complex casting the lubricants can be more difficult to be flushed out by the metal into the overflows. So it is not clear that Lindsay and Wallace's conclusions could be applied to all castings.

Die lubricants used in the die casting industry mostly have a formulation comprising polymer wax, silicone oil and some surfactant, and are usually diluted with water. Some diecasters also use external water to quench the die surface for a complex casting. This water, when not removed either by evaporation or with compressed air before die closure, turns into steam in an explosive expansion when metal arrives in the die cavity according to Walkington (1997). As was argued above for lubricants, more complex dies would be expected to increase the likelihood of retaining water in pockets of the die.

The amount of gas present in a high pressure diecasting varies both with part geometry and casting parameters. Typically, the gas contents inside high pressure diecast parts are reported to vary between 10 and 50 cc/100 g (cubic centimeter per 100 g of aluminum at standard temperature and pressure) according to Badini et al. (2002). By the use of vacuum diecasting, gas contents below 10 cc/100 g and even as low as 1 cc/100 g may be achievable,

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facilitating conventional heat treatment and allowing parts to be welded.

Due to the difference of hydrogen solubility between the liquid phase and the solid phase of aluminum, hydrogen in the metal will be released during the metal solidification. The maximum release of hydrogen can only account for less than 3% (1 cc/100 g) of the casting volume (calculated from Campbell, 1991). In the practice, the liquid metal is either degassed or protected to minimize the hydrogen intake. So the hydrogen content is minor when compared to the gas from other sources, for example, air in the cavity as discussed above.

Sakamoto and Sose (1985) reported that the gas contents were 3–5 cc/100 g for castings made using a GF (Gas Free) valve with vacuum applied, and 6–10 cc/100 g for those when the GF valve was used as an air vent. Brevick and Cheng (1995) reported that the gas content in an experimental casting was on average 2.6 (in the range of 2.05–2.73) cc/100 g for vacuum assisted and 6.3 (5.12–21.5) cc/100 g when the Fondarex vacuum system was used as an air vent.

A number of methods may be used to quantify the gas level in castings. The Archimedes test is commonly used as a non-destructive method to measure casting density. While the average density is a good measure of pore volume fraction, it does not accurately reflect the amount of gas in a casting. The gas pores would typically be merged with shrinkage pores and their relative contributions difficult to separate. The density measurement is therefore considered to be inadequate for an accurate estimation of gas content in the castings.

Yamamoto et al. (1989) estimated the gas content by heating and remaining the castings at 495 °C for 4 h and then measuring the casting density when blisters were formed on the surface of the castings. However, the mechanism of the blister generation was very complicated and could be affected by many factors, such as the casting shape, the location of gas pores in the casting (a gas pore in the centre might not show up) and even the way the casting was placed in the furnace during heating. Again, this method is considered not ideal to estimate the gas content in the casting.

Vacuum fusion (Sakamoto and Sose, 1985; Murray et al., 1991) is a more accurate method to determine the gas content. With this method, a small sample sectioned from a casting was placed in a container under vacuum and heated until molten. The gas in the sample was then released and the gas content could be calculated from the pressure increase due to the gas release. In a variation of this technique, Brevick and Cheng (1995) placed the whole casting in a bell jar and heated it in a furnace.

Gas content in a casting is an effective indicator of casting quality and in general, provides a good indication of the suitability for post casting processes such as welding and heat-treatment. The current study describes a vacuum fusion rig, together with measurements of the gas contents in complex castings produced under varied industrial conditions.

## 2. Experimental

The principle of the vacuum fusion method is that a sample is placed in a sealed vessel and melted under vacuum. The gas content in the sample is determined from the pressure increase due to gas released from the casting. In the method, sealing of the vacuum vessel at the melting temperature is critical to minimize the error due to the air ingress into the vacuum vessel. Effort was made to achieve the best sealing under the operational temperature and pressure. The vacuum vessel was made of mild steel and consisted of two halves. Each half had a shape like a flat pan and had a wall thickness of 20 mm to reduce distortion. The two halves were fastened together using mechanical fastening. A copper ring was used as a

gasket between the mating faces. A knife-edge rim was machined on the mating face of each half of the vessel, but slightly offset. The rims would therefore bite into the copper ring to seal the vessel when the two halves were tightly engaged together. A stainless steel pipe from the top of the vessel was connected to a vacuum pump and an argon supply. The pipe passed through a water tank to release the heat conducted from the furnace. A pressure transducer was connected to the pipe to record the gas pressure. A 1.5 m long by 2 mm diameter thermocouple was inserted through the pipe into the vacuum chamber to monitor the temperature inside the vessel. By sharing the same port with the pipe on the lid, the potential leak using an extra port for the thermocouple was eliminated. Swagelok fittings were used for all pipe joints. With all of these measures applied, the leak rate of the vessel at the melting temperature could be controlled at less than 6 mbar/h with an average of 4 mbar/h. The pressure increase of a typical test was approximately 300 mbar and the melting process took less than 2 h. The error due to the air leak was calculated to be less than 4% on average. A schematic diagram of the apparatus is shown in Fig. 1.

A stainless steel pan was placed in the vessel to contain the casting sample. The pan could load 2 kg of aluminum, which was slightly more than the weight of the whole castings mostly investigated in this study. For castings larger than 2 kg, segments were sectioned from the casting to fill the pan as much as possible. Having a larger ratio of metal filling the open space of the system meant that the pressure gain due to the gas release would be relatively higher. The total volume of the pipe lines in this test rig was less than 2% of the vacuum vessel. For a pressure sensor having an error of  $\pm 0.2\%$  of the full range, the accuracy is calculated to be  $\pm 0.02$  cc/100 g. The whole vacuum vessel was placed in a furnace in which a uniform temperature was maintained. The temperature inside the vessel was used in the calculation of the gas mass. The error caused by the difference of temperatures between the gas in the pipes and the vessel was negligible due to the small volume of the pipe compared with the vessel.

In the test, the vacuum vessel loaded with the sample was preheated in the furnace at 150 °C for 4 h with the vacuum pump continuously on. During this period of time, the system was flushed with argon twice. The casting was then held at 450 °C in the furnace for another 1–2 h to remove any surface volatiles. Having been checked to meet the leak criteria mentioned above, the furnace was then set to 630 °C until the casting became completely molten. During this melting process, the vessel chamber was isolated from vacuum by manually switching off the valves. The temperature and pressure in the chamber were recorded online. The total gas released from the sample could therefore be determined from the difference between the maximum and the initial pressure.

The casting investigated in this study was a pump cover with a complex geometry, as shown in Fig. 2. The casting was produced in an industrial die-casting machine, with vacuum applied during normal production. To investigate the gas contribution from different sources, the machine operational parameters were varied from the normal conditions. These included eliminating combinations of the following steps: vacuum, tip oil, die spray and external quench water. In order to maintain the thermal balance of the die, each of these samples was collected between the normal production shots. Samples were also collected by ladling the metal from the holding furnace directly into the stainless steel pan, and also by pouring and solidifying the metal in the shot sleeve with the plunger tip remaining stationary between two normal production shots.

## 3. Results and discussion

A typical result with the traces of pressure,  $P(T)$ , and temperature,  $T$ , is shown in Fig. 3. The time was counted from the end

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