Effectiveness of the Vacuum Technique in Pressure Die Casting

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Porosity caused by air trapped in castings (blowholes) accounts for a large share of rejects in pressure die casting. The defects are discovered after machining, threading or tightness testing and are very costly.

The vacuum technique in pressure die casting has been in existence for a very long time — some companies were proposing installations as early as 1960. Many still wonder about the effectiveness of the vacuum technique. For this reason, pressure die casting tests were performed to measure the effect of applying a vacuum to the castings. The level of the vacuum applied in this study is about 150 mbar (the classical vacuum). Pressure drop curves and density measurements enabled us to compare the porosity levels with different parameters and to evaluate the utility of this technology.

Experimental Conditions

The casting is a plate (100 x 400 x 2mm) having two rows of bosses and one row of bars. The sizing of the vacuum circuits complies with all technical recommendations. During the pressure drop measurements by "dry-run injection (without metal)," the die was fitted with a pressure sensor (0-2 bars).

The process parameters (speeds, strokes, pressures, injection profiles, die and metal temperature, vacuum) were checked at each injection. The castings were made of AlSi9Cu3(Fe), EN AB 46000.

Experimental Methods Recording of Pressure Profile in the Cavity

These measurements were made without any injection of metal. The typical pressure profile in the die (see figure 1) exhibits three specific zones: Zone I, pressure drop; Zone II, pressure equilibrium between the die cavity, the vacuum tank and the vacuum pump; Zone III, the vacuum system is vented (disconnected from the vacuum tank and vacuum pump). The pressure rise makes it possible to evaluate leaks from the die. Each curve is the mean of at least three records. The differences between the curves are not significant.

The comparison parameters are:

1. The minimum pressure value reached (this value is regarded as having been reached when the difference between two consecutive values does not exceed 5 mbar).
2. The pressure drop time (this is the time the pressure takes to reach the minimum value).
3. The pressure drop rate (mbar/s) when the vacuum is first applied (in the linear part of the curve).
4. The rate of pressure recovery to atmospheric pressure when the vacuum is stopped.

The various tests performed are grouped and the positions of the circuits are shown in table1.

Test Nº	Plunger Speed (stage 1)(m/s)	O-ring in joint plant	Vacuum During Injection	Upperside side circuits	Lower side circuits	Top circuits	Total Sectional Area of Venting	Type of valve
1	0.1	no	yes	open	open	open	110 mm^2	valve mechanical pulse
2	0.4							
3	0.1	yes						
4	0.4						77 mm^2	
5	0.1	no			close		44 mm^2	
6				close			77 mm^2	
7				open	open	close	110 mm^2	
8	0					open		
9	0.2 (phase 1) + 2.5 (phase 2)						10 mm^2	
10		yes	yes				0 mm^2	
11							110 mm^2	
12							1.2 mm^2	
13								
14							110 mm^2	
15			no					
16		no					80 mm^2	massive venting
17	0.1							

Table 1 — *Testing program: pressure drop measurements indic (without metal)*

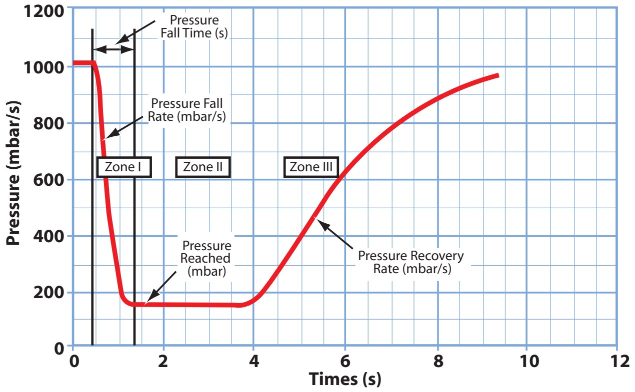

Fig. 1 — *Typical pressure vs time profile mold.*

Density and Porosity Measurements

Castings were sampled according to various parameters studied (see table 2). For each test, three castings underwent density measurements in the following parts: one density in the gating system, six densities in the bosses (one row of bosses) and six densities in the plates (plane parts) between the bosses. The porosity values were calculated from the densities: $p = (d_o - d)/d_o$, where d_o ($d_o = 2.777$) is the maximum density of the mean of the three values for each element (plate or boss). Each stated porosity is the mean of 18 values.

Results of the Analysis Vacuum Measurement Results Influence of Stage I Plunger Speed

Test N°	Plunger Speed (stage 1)(m/s)	Speed Gate	Lower Side Circuit	Stage 1 Vacuum	Stage 2 Vacuum	Type of valve
1	0.2	45	open	yes	yes	mechanical pulse
2	0.4					
3	profile 1*					
4	profile 2*					
5	profile 1	30				
6		60				
9-7		45				
10-8					no	
11-9	0.2			no		
12-10	profile 1					massive air venting
13-11				yes	yes	
15-12			closed			mechanical pulse

Table 2 — *Testing program on actual casting - density measurement.*

The influence of the plunger advance speed on the pressure drop was examined. It was found that the pressure drop is larger at a plunger advance speed of 0.1 m/s than at a speed of 0.4 m/s (see table 3). In effect, the faster advance of the plunger results in a larger back-pressure in the die and a slower pressure drop.

If the plunger remains immobile (test 8) the pressure drop is small and the pressure reached is unsatisfactory. It seems, then, that the displacement of the plunger partially offsets the leakage from the die. It is therefore best to adjust the stage I speed to the slowest speed compatible with the leakage from the die without creating problems of premature solidification of the metal in the shot sleeve.

Plunger Speed Vp (m/s)	Pressure Drop (mbar/s)	Pressure Reached (mbar)
Test 1 — Vp = 0.1	1637	156
Test 2 — Vp = 0.4	1395	161
Test 8 — Vp = 0	953	564

Table 3 — *Influence of stage I plunger speed on pressure drop.*

Plunger Speed	Pressure Reached (mbar)	Pressure Drop (mbar/s)	Pressure Recovery (mbar/s)	Pressure Reached (mbar/s)
Vp = 0.1 m/s	Test 1 (without seal)	1637	234	156
	Test 3 (with seal)	1649	231	172
Vp = 0.4 m/s	Test 2 (without seal)	1395	234	161
	Test 4 (with seal)	1413	229	154
Vp = 0.2 + 2.5 m/s presence of stage 2	Test 15 (with seal)	1544	84	68
	Test 16 (without seal)	1533	100	78.4

Table 4 — *Effect of O-ring in joint surface.*

Test n°	Total Vacuum Cross-Sectional Area mm^2	Pressure Droped (mbar/s)	Pressure Reached (mbar)
1	110	1637	156
5	77	1324	179
7	66	1255	190
6	44	1230	157

Table 5 — *Effect of vacuum cross-sectional area and air vent location.*

Effect of the Presence of an O-ring at the Joint Plane

We placed an O-ring around the die cavity to measure the leaks that may exist at the joint surface. The presence of the joint does not affect the pressure drop (see table 4) in the vicinity of 150 mbar. On the other hand, with a higher vacuum (around 70 mbar – tests 15 and 16), the joint has a rather clear positive effect on the pressure reached in the cavity (-11 mbar) and on the pressure recovery rate (-16 mbar/s).

Effect of Vacuum Cross-Sectional Area and Air Vent Location

Naoyuki Tsumagari has clearly demonstrated, on a laboratory set-up, the importance of the cross-sectional area of the vacuum channels on the pressure drop in a die. He has also shown that the length of the channels (regular losses of head) has much less effect on the vacuum.

The pressure drop decreases as the total cross-sectional area of the vents is increased. The pressure level reached shows the effect of the losses of head (table 5). In test 6, where the cross-sectional area of the vents is the smallest, the vacuum level reached is correct. In effect, the losses of head in this case are smaller because the air does not change direction during its evacuation. Preference should therefore be given to channels having a simple geometry.

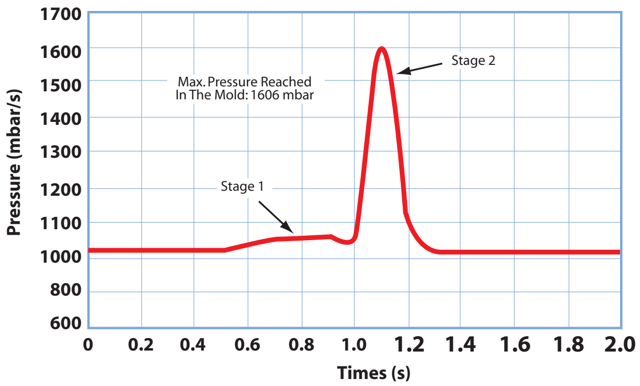

Fig. 2 — *Evolution of pressure in mold with 10mm^2 venting and no vacuum.*

Test n°	Total Cross-Sectional Area of venting (mm^2)	Pressure Reached in Die (mbar)
1	0	> 2000
5	1.2	1852
7	10	1606
6	110	1132

Table 6 — *Effect of total cross-sectional area ventings (without vacuum).*

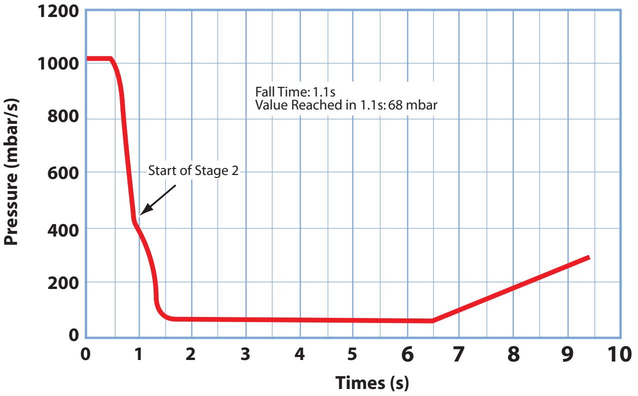

Fig. 3 — *Influence of vacuum hold in stage 2.*

Pressure in the Die Without the Vacuum

In a die without a vacuum system, removal of the air is very difficult in injection stage 2. Charles H. Bennett calculates a pressure of two bars in a die with a venting cross-sectional area of 14mm^2 under the usual pressure die casting conditions. We found similar values in an actual test (see figure 3 – test 10): a pressure of 1.6 bars for a venting cross-sectional area of 10mm^2. Other values are given in table 6. It can be seen that only very large venting cross-sectional areas (110mm^2), substantially equal to 3/4 of the gate cross-sectional area (1.6 x 100mm^2), can prevent the excess pressure in the cavity during injection.

Influence of Vacuum Hold Time During Injection Stage 2

When the vacuum is held for the whole duration of the injection (stages 1 and 2), the high plunger speed has very little effect on the evacuation of the air (see table 4 – test 15). It is thought that, for castings in which very low porosity is required, it is beneficial to hold the vacuum in stage 2.

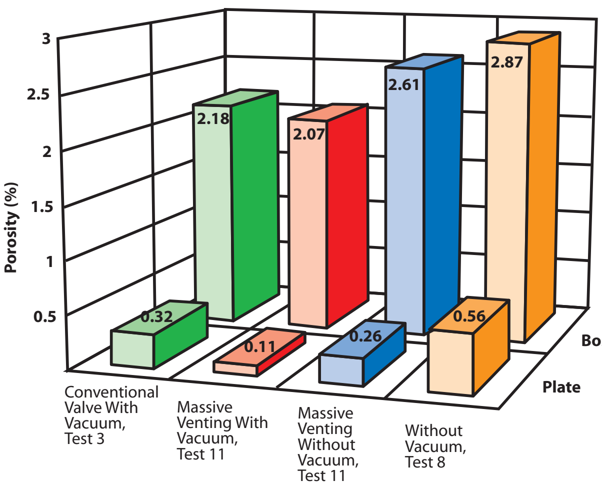

Fig. 4 — *Test with and without vacuum.*

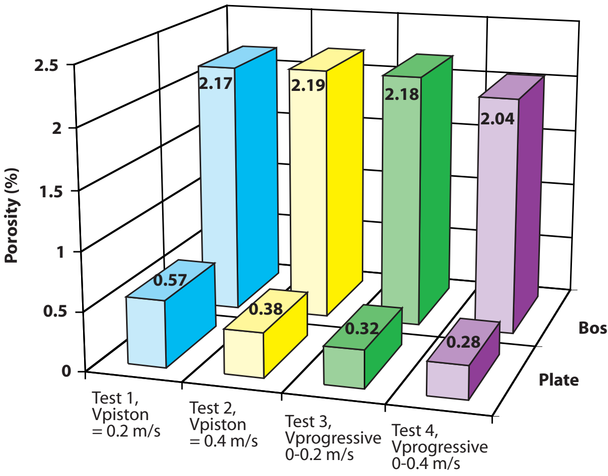

Fig. 5 — *Influence of stage 1 filling profile.*

Establishment of the Vacuum Through Massive Venting

A series of pressure drop recordings was made through a massive venting block having a cross-sectional area of 80mm^2 (0.8 x 100mm). The vacuum level reached is quite satisfactory but the pressure drop time is substantially twice as long as with a mechanical pulse valve. This same phenomenon is observed in N. Tsumagari's study. The pressure drop is less than in the tests performed with the pulse valve (see table 7). It seems that the sawtooth shape of the venting block slows the evacuation rate. It is therefore prudent to allow a longer vacuum time when massive venting blocks are used (stage 1 speed slower or stage 1 stroke longer).

Density and Porosity Measurement Results on Castings Effectiveness of the Vacuum

Tests were performed with and without the application of the vacuum. The effectiveness of application of the vacuum is clearly shown (see figure 4). There is no porosity caused by shrinkage cavities in the plane parts. On the other hand, in the bosses there are shrinkage-cavity-type defects in addition to blowhole-type porosity.

Test n°	Pressure Drop (mbar/s)	Pressure Reached (mbar)	Fall Time (s)	Type of Valve	Vacuum Cross-Sectional area (mm^2)
17	1105	133	2.1	massive air venting	80
5	1325	179	1.2	impulsion valve pulse	77
7	1255	190	1.2	impulsion valve pulse	66
1	1637	156	0.7	impulsion valve pulse	110

Table 7 — *Establishment of vacuum through massive venting.*

Test n° (vacuum)	Porosity (%) Test 3 (with vacuum)	Porosity (%) Test 8 (without vacuum)	Reduction of Porosity
plate	0.32	0.56	44%
boss	2.18	2.87	24%
mean of casting	1.25	1.72	27%

Table 8 — *Reduction of porosity with vacuum.*

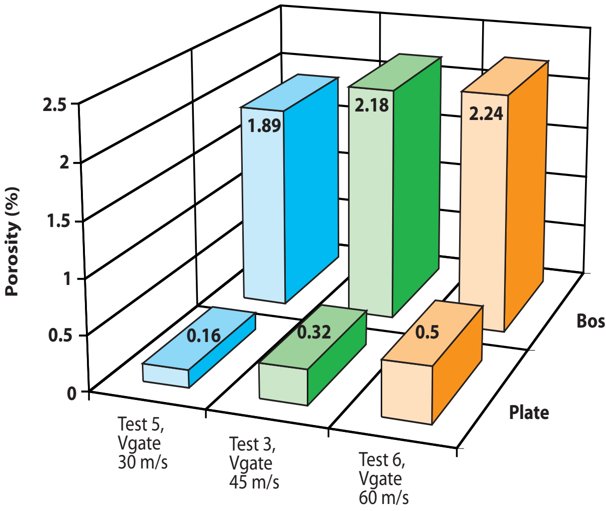

Fig. 6 — *Influence of velocity at gate.*

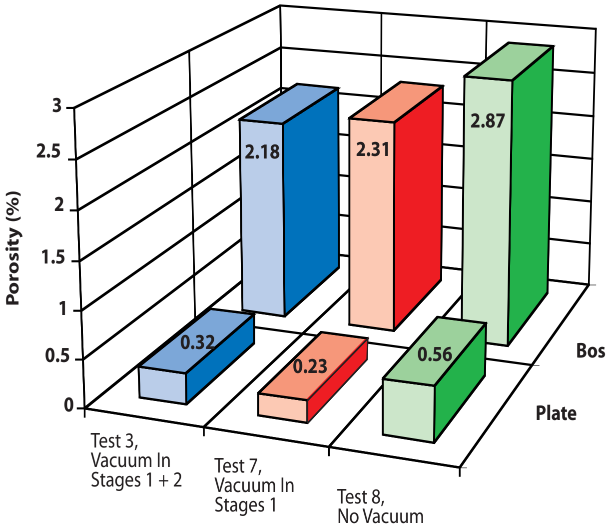

Fig. 7 — *Effect of vacuum hold in stage 2.*

With the optimum stage I injection conditions (plunger displacement at constant acceleration), a mean reduction of porosity of 44 percent is obtained in the plane part of the casting and 24 percent in the bosses when the vacuum is applied (see table 8). The overall mean reduction of porosity is 27 percent.

Castings generally have more complex shapes than the casting studied, so the reduction of porosity will be smaller.

Influence of the Stage I Injection Filling Profile

In this study, four stage I injection filling profiles were tested:

- Plunger advance at constant speeds of 0.2 and 0.4 m/s,
- Plunger advance at constant accelerations from 0 to 0.2 m/s and from 0 to 0.4 m/s.

	Test 3 vacuum in stage 1 and 2	Test 7 Vacuum Stage 1	Test 7 Vacuum Stage 1
Global Mean Porosity of Casting (Basses + Plates)	1.25%	1.27%	1.75%

Table 9 — *Influence of stage 2 vacuum hold.*

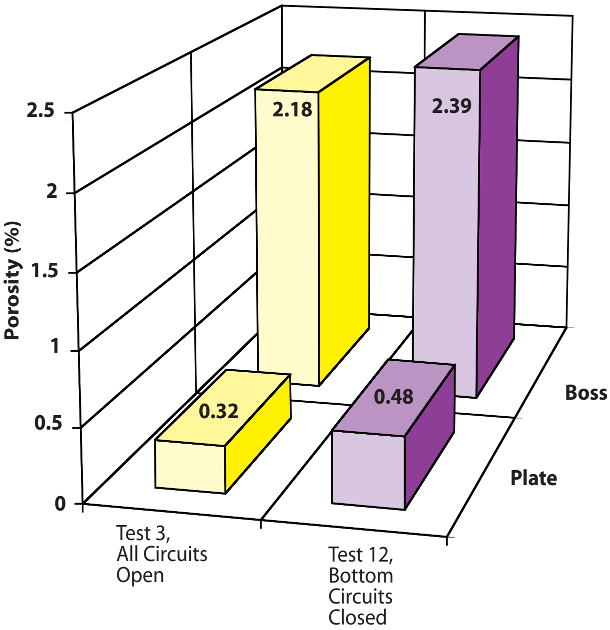

Fig. 8 — *Influence of locations of vacuum ports.*

A constant-acceleration speed profile keeps the wave that forms in the shot sleeve in front of the injection plunger and considerably reduces the trapping of air in injection stage I. In effect, the porosity values are lower in tests 3 and 4 (see figure 5). In tests at constant acceleration, a higher speed seems to give the best results.

Influence of Stage 2 Speed

Three speeds of the metal at the gates were studied: 30, 45 and 60 m/s. These speeds are compatible with a sprayed flow during filling. There is a marked increase of porosity when the speed at the gate increases. Injecting in stage 2 at the lowest speed possible in the sprayed regime, but fast enough to avoid misruns and cold laps, is recommended. Too fast a speed quickly obstructs the air vents.

Effect of Holding the Vacuum in Injection Stage 2

When the vacuum is held in injection stage 2, better evacuation of air from the deep parts is noted (the porosity of the bosses is higher in test 7 than in test 3 – see figure 7). On the other hand, the flow is perturbed in the plane part of the casting (the porosity of the plates is higher in test 3 than in test 7). The mean global porosity of the casting is lower when the vacuum is held in stage 2 (see table 9).

Influence of Vent Locations

Tests were performed with the bottom air vents obstructed. Porosity measurements on castings show poor evacuation of air. Adding suction ports increases the air evacuation capacity.

Test n° (vacuum)	Porosity (%) Test 11 (with vacuum)	Porosity (%) Test 10 (without vacuum)	Reduction of Porosity
plate	0.11	0.26	58%
boss	2.07	2.60	20%
mean of casting	1.09	1.43	24%

Table 10 — *Porosity level with and without massive venting.*

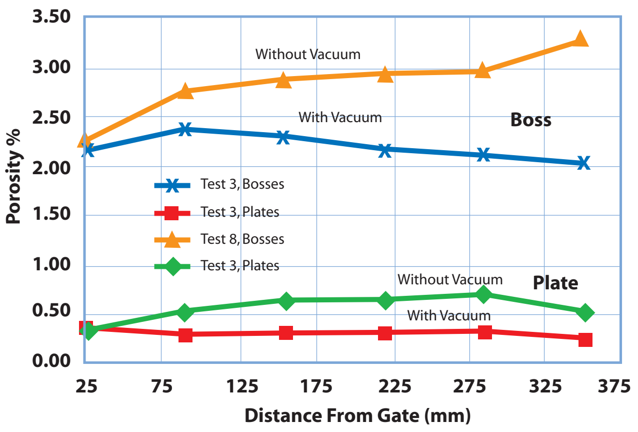

Fig. 9 — *Porosity vs. distance from gate.*

Effectiveness of Massive Venting With and Without Vacuum

A massive venting system was made with water cooling circuits. The vacuum cross-sectional area through this block is 80mm^2 (0.8 x 100mm). The test results show a very low porosity level when the vacuum is applied. In the absence of the vacuum, the porosity level in the plane part (plates) is rather low, but it was found that air is not correctly evacuated from the bosses. By contrast, massive venting associated with the vacuum yield a very good improvement in both the bosses and the plates (see table 10). In the plates, massive venting can result in lower porosity (0.26 percent) than a classical vacuum (0.32 percent). Massive venting and the vacuum together yield a very low porosity level (0.11 percent).

Porosity in Casting Versus Distance From Gate

The porosity was studied as a function of distance from the gate (see figure 9). When the vacuum was applied, the trend was to lower porosity with increasing distance from the gate, the reverse of what is found without the vacuum. Many studies confirm this finding. Therefore, the vacuum can be an effective way to reduce porosity in the last zones filled.

Conclusions

This study clearly shows that the vacuum is effective. The casting studied is simple in shape in the plane part, and the gating system allows good evacuation of the air from the die in this zone. Even so, there is a clear difference in porosity between the cases with and without application of a vacuum. In the bosses, however, which are more massive, the improvement contributed by the vacuum is smaller than in the plane parts.

The following results may be noted:

1. The stage 1 speed must be slow enough to allow sufficient vacuum application time and fast enough to attempt to offset leakage from the die. A speed profile with constant acceleration reduces the trapping of air of the shot sleeve in injection stage 1.
2. In stage 2, injecting at the lowest speed possible in the sprayed regime, but fast enough to avoid misruns and cold laps, is recommended.
3. Holding the vacuum in stage 2 allows better evacuation of air from isolated deep parts, but tends to perturb the flow during filling and seems to aggravate the porosity in the thin parts of the casting.
4. Massive venting in combination with the vacuum gives excellent results.
5. With a classical vacuum level (~150 mbar) the use of a seal does not influence the evacuation of air. An effect becomes perceptible only with a higher vacuum (~50 mbar).
6. Porosity measurements on castings show that the locations of the vents in the die are important. It might accordingly be worthwhile performing a numerical simulation of filling to know which zones are filled last before designing the vacuum channels.
7. Applying a vacuum is very effective at reducing porosity in end-of-filling zones.