GAS POROSITY

A Guide to Correcting the Problems

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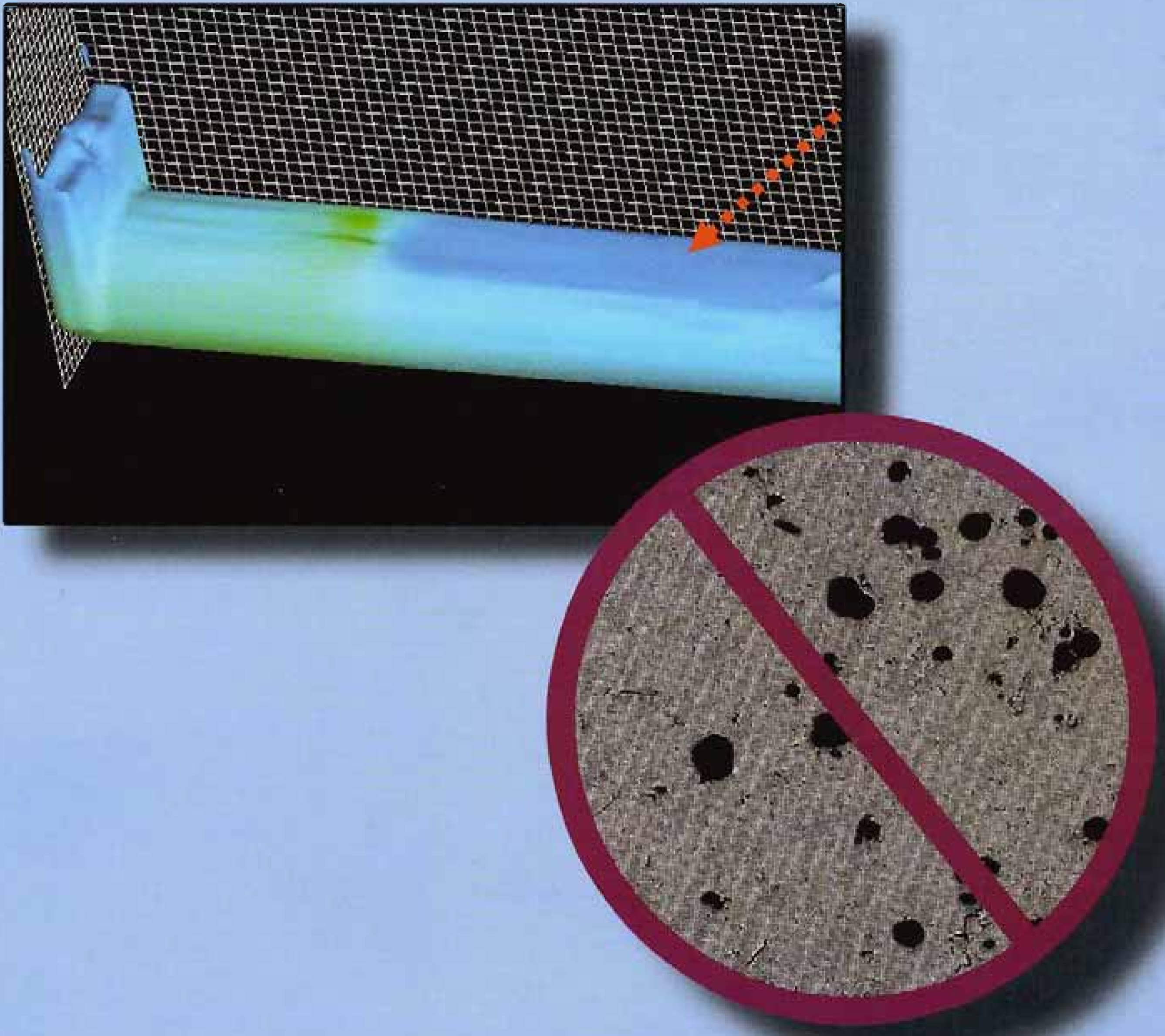

Publication: 516

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GAS POROSITY –
A GUIDE TO CORRECTING THE PROBLEMS

IDENTIFICATION

The first step in any defect analysis is to identify the problem. There are several kinds of porosity that can look similar, so it is absolutely critical to identify the most likely cause before starting the troubleshooting process. A wrong judgment (for example, judging porosity to be shrink when it is really gas) can result in all the corrective efforts being totally wasted. Thus, it is extremely important to examine samples of the porosity carefully (using magnification if necessary) before corrective action starts.

Gas porosity is probably the most common type of porosity in die casting. The primary identification of gas porosity comes from the appearance. Identification can be quick and relatively easy in many (but not all) cases. Identification always requires sectioning and examination of the porosity and it often requires some magnification. Usually 8-to-10 power is sufficient for most situations — every die cast shop should have a 50 power stereo microscope available for quicker and more accurate defect identifications. (These microscopes are relatively inexpensive.) The user does not have to be a trained metallurgist for this kind of defect identification, a little experience will suffice very well.

The easiest identification case is when the porosity appears as round bubbles, shown below. Not all cases will be this easy and there will be some mistakes made, but regardless, the best effort at identification should always be done before starting corrective actions.

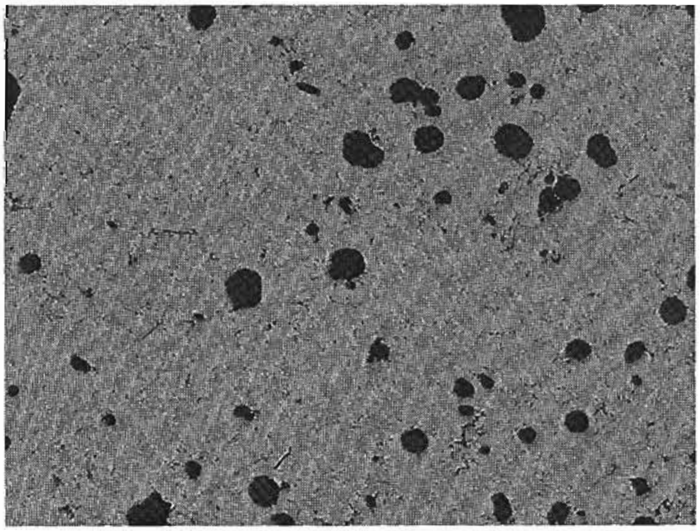

Figure 1: *Gas porosity is round with smooth walls (sometimes shiny) and often grouped together (but not always). It <u>is not</u> sharp, jagged or crack-like in appearance.*

The key to the identification is a round, smooth walled shape (think bubbles). Sometimes it is shiny, sometimes not – but it is a smooth wall.

Gas porosity is often rather random in location, and can move around, but sometimes it is grouped together consistently in one spot. (This is a clue as to the source of the porosity, see the following descriptions.)

The identification features noted above may not always be present – for example, there can be some trapped gas in shrink porosity, which is very jagged and irregularly shaped – but for the most part, if the primary cause of the porosity is trapped gas, then the porosity will have smooth walls and the bubble shape. See the following illustration.

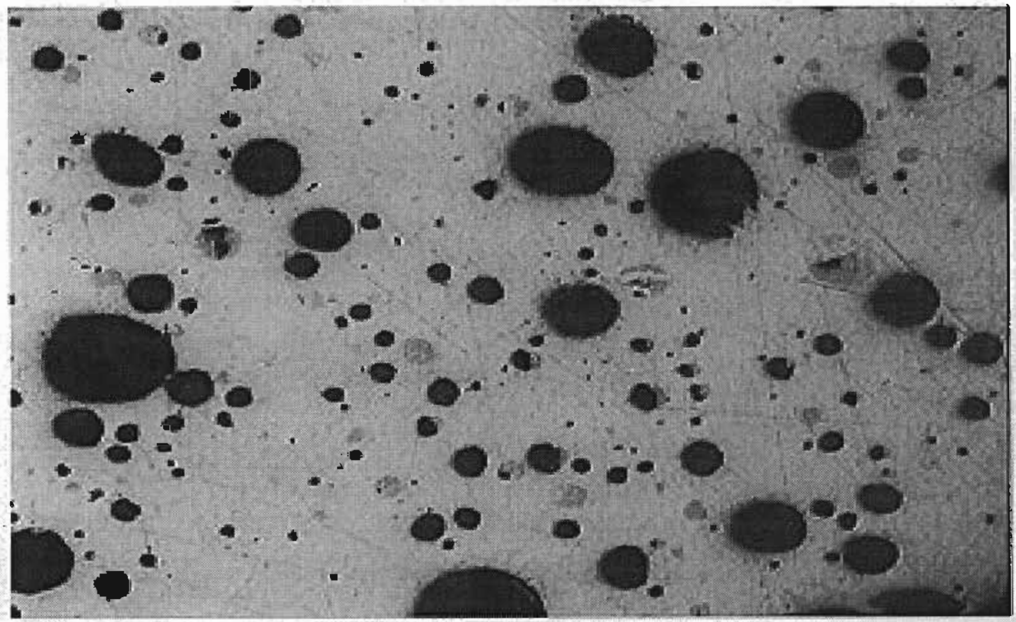

Figure 2: *Pure gas porosity. The high concentration of gas bubbles is probably caused by too much lubricant, or from water leaking into the die. (J. Brevick, X50).*

We will come back to the sources of the trapped gas, but first we will discuss some other kinds of porosity that either look like gas porosity or also contains trapped gas – and where gas porosity is a factor but not necessarily the primary cause.

FLOW POROSITY AND GAS POROSITY

Flow porosity is different from gas porosity, although it is frequently closely associated with gas porosity, and is mentioned here because it will often look very similar to gas porosity.

Flow porosity is generated when two metal flows come together and some space is left between the flows. This happens when there is an oxide skin (for aluminum or magnesium), or a skin formed by some solidifying metal on the edge of the metal flow front. This skin may prevent a complete mixing of flows and will function to keep the flow surfaces from mixing homogeneously. This surface, or skin, can also help bridge over openings and maintain some separation between metal flows.

These areas of porosity may have smooth surfaces like the trapped gas porosity, so the surface of the flow porosity hole may look the same as the smooth surface of a gas porosity hole. However, the flow porosity will have sharp corners where the flows come together, and the fact that the hole was formed from two skins coming together will be apparent under magnification. Probably a magnification of 8-to-10 power is sufficient. See Figure 3.

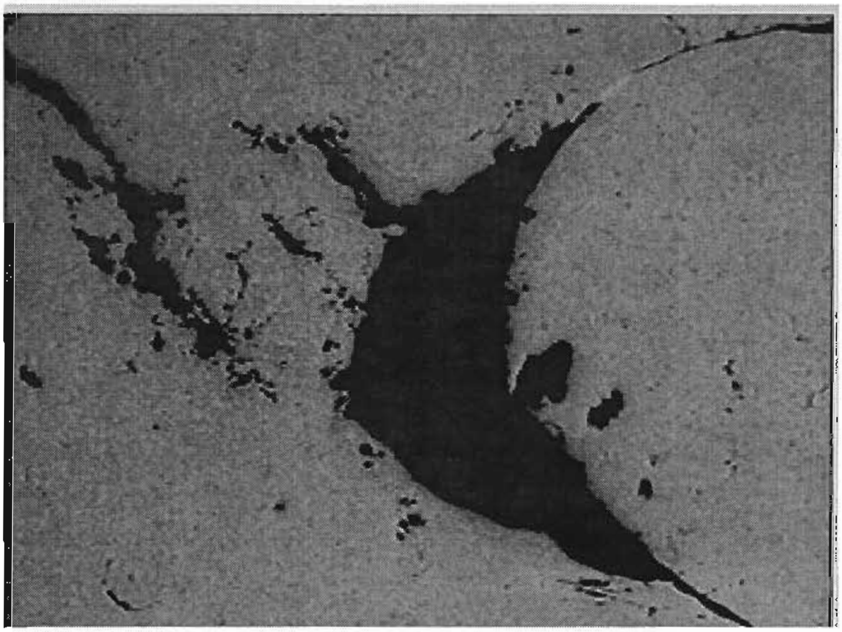

Figure 3: *Typical flow porosity. This is usually formed by a gap between different metal flows. (J. Brevick, X50).*

There can be an excess of gas porosity developed at the leading edge of a metal flow path (depending on the turbulence and speed of the metal) – this gas porosity may be associated with flow porosity, and may be in the same area. This type of gas porosity will usually appear to be concentrated towards the end of the flow path, wherever that is. (In some cases, this can be in a blind or dead end shape that may not be too far from the gate.) One way to visualize it is to think about a little bit of froth at the leading edge of the metal flow.

This type of gas porosity will usually appear as a group of bubbles at the leading edge of the metal flow. A frequently used correction for this problem is to try to get this leading edge into an overflow. Whether this is successful or not depends on many things – including the location and size of the gate to the overflow, the metal flow direction at the end of flow, the temperature of the metal and the die, etc.

For the troubleshooter, the first thing is to establish is whether the porosity occurs at the end of a flow path. The best way to predict flow paths is to use simulation; however, a short shot may also help to identify the end of flow. Another method that can sometimes help (but not always) is to apply a lot of heavy, black grease in the gate area, then watch to see where the black streaks go. Adding an overflow at the end of the flow path can often clear up this kind of porosity.

However, if the flow arrives early in the fill sequence, there will not be much pressure on the metal to push it through a thin gate to the overflow until the cavity is almost full, so the overflow may not be as effective. In this case, the gate to the overflow should be as big as possible.

Overflow gates arte usually about 0.03 to 0.07 inches (0.75 to 1.75 mm) thick in aluminum, and about half that size in zinc. One of the most common practices in the use of overflows is to raise the temperature of the die in a specific area. This also keeps the gate to the overflow open – consequently, using large overflows may be required in a colder area of the die.
Using good gate design techniques so there are a minimum of jet type metal flows that lead the rest of the flow is important, and can minimize this type of gas porosity. Figure 4 and Figure 5 show some of this type of porosity.

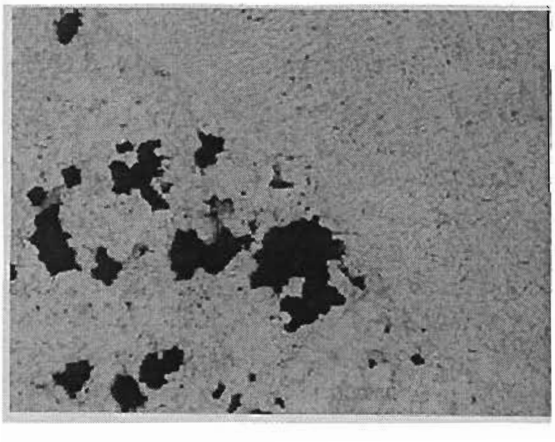

Figure 4: *Combination of shrink and gas porosity at the edge where two metal flows have come together. (J. Brevick, X50).*

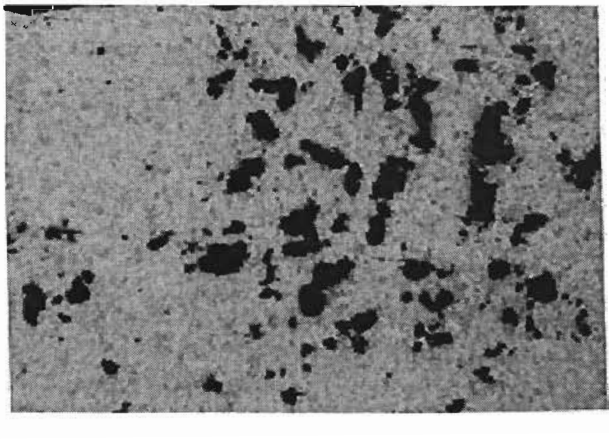

Figure 5: *Mostly gas porosity pushed into an overflow. The metal flow comes from the upper left. (J. Brevick, X50).*

PRESSURE AND GAS POROSITY

Since trapped gas is a common problem in die casting, and some other kinds of porosity can be corrected by increasing the metal pressure, this correction is also frequently applied to trapped gas. However, metal pressure should be used cautiously where the trapped gas porosity is identified as the major factor. This is because gas porosity is not always easily corrected with metal pressure. However, shrink porosity and flow porosity will respond quite well to metal pressure applied at the right time and place.

The reason for this is the geometrical relationship between pressure and the size of the bubbles. Using the gas law to calculate the change of volume with pressure, and calculating the radius of a sphere from Vol = π r3 , we can show how the visibility of the gas bubble is affected by metal pressure.

For example, if there were a bubble with a radius of 1.66 inches at atmospheric pressure, the radius would be about 0.2 inches at 9000 psi. In other words, the pressure changes by a factor of 600 times, but the radius changes by only about 8.5 times. Because of this relationship, further increases in metal pressure will make less and less difference in the visibility of the porosity. Thus, it is easy to get to the point where there can be many problems with flashing as well as other problems caused by the increase in pressure, but the pressure will make much difference in visible gas porosity. Continuing with this example, if the pressure was increased to 12,000 psi, about a 30% increase, the bubble size would only decrease another 9% to about 0.18 inches diameter (which would not make much difference in the visibility of the bubble).

The same relationship keeps the bubbles relatively large even if the volume of gas spreads-out into many bubbles. For example, if the volume of trapped gas in the shot sleeve were 2.5 cubic inches (it is very easy to trap this much gas in the shot sleeve) and all this trapped gas were in one big bubble, the diameter of the bubble (at about 9000 psi final pressure) would be about 0.23 inches. But, if this volume were broken into 20 smaller bubbles of equal volume, then each of the 20 smaller bubbles would still be 0.088 inches in diameter – and this is a lot of very visible porosity.

Thus, even a small amount of trapped gas can generate a lot of very visible porosity, and increasing the final pressure may have very little effect on the size of these bubbles.

A difficult aspect of this issue is that the gas and shrink porosity often occur together. In this case, adding pressure can be of some benefit to the shrink porosity component. Pictures on the following page show some shrink and gas porosity located together. This is a common situation, and can be confusing because the troubleshooter does not know whether to work first on the gas porosity or the shrink porosity.

In this case, it would be desirable to make sure that the cavity pressure is within the range needed for minimizing shrink porosity. However, even if the pressure calculations show that the pressure from the injection system is proper and is available, it still does not guarantee that there will be pressure available at the specific location(s) in question. It will depend on the temperatures, on when the gate freezes, the distance from the pressure source to the specific location, and a number of similar factors.

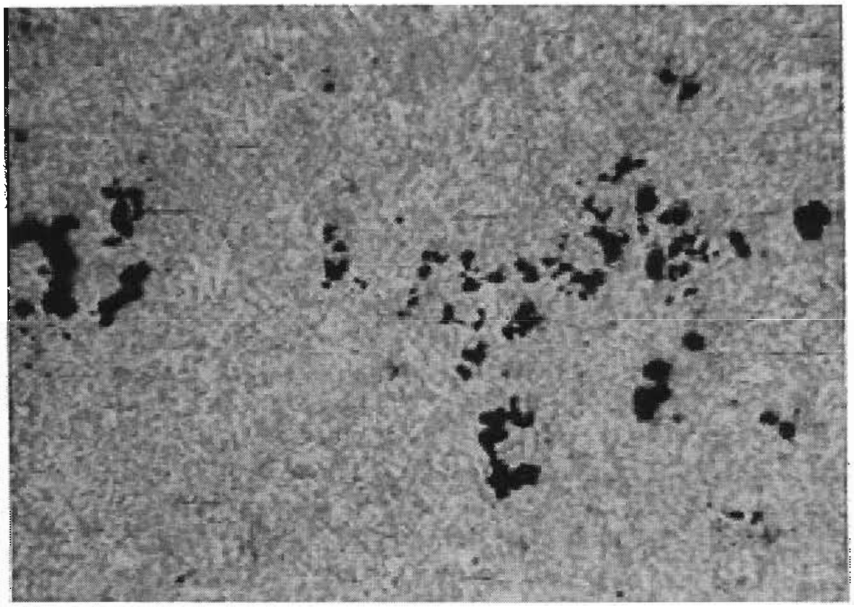

Figure 6: *Mostly shrink porosity with some gas probably present — note the jagged, irregular shapes. (J. Brevick, X50).*

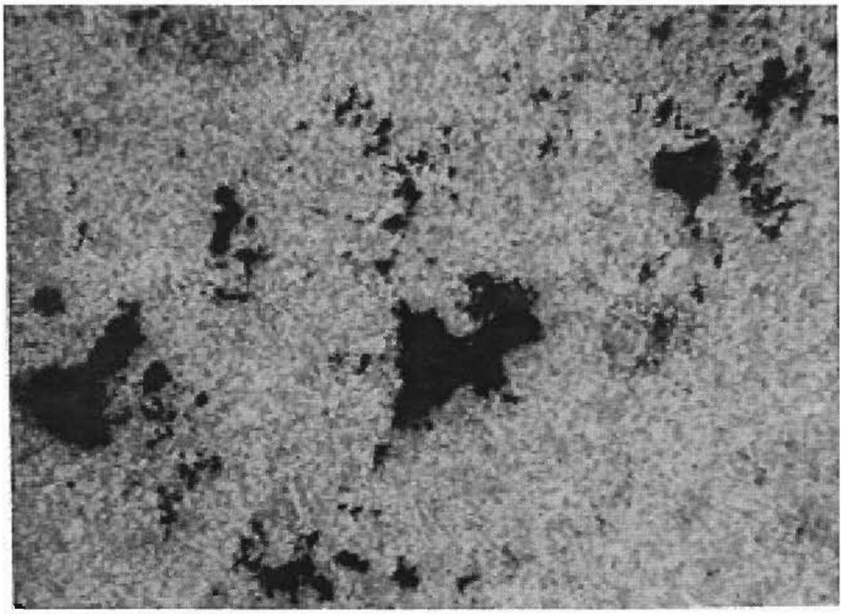

Figure 7: *Same magnification as Figure 6. Shrink porosity with noticeable gas porosity also present. Note that the size of the porosity holes are larger and more rounded with more gas present. (J. Brevick, X50).*

While increasing the metal pressure can be a factor in these cases, identifying whether gas or shrink porosity is the highest contributing factor is not easy, and which action to take may never be clear-cut. However, if this situation of mixed shrink and gas porosity does exist, the following actions would be suggested:

1. Review the metal pressure situation. Two metal pressure situations are important, one without intensification and the final pressure with intensification. The minimum metal pressure for all aluminum and magnesium castings is recommended to be 3000 psi (200 bar), and for zinc about 2000 (140 bar) psi. This pressure is the static pressure at the end of the stroke — before the intensifier comes in. Where there are specific porosity concerns, this static pressure should be about 4000 to 6000 psi (275 to 400 bar) for aluminum and magnesium. Usually about 3500 psi (250 bar) is recommended for the more porosity sensitive parts in zinc.

   The intensified pressure will normally be 2.5 to 3 times the static pressure, which would be about 10,000 psi (666 bar) to about 15,000 psi (1000 bar). Often a minimum intensified pressure of 10,000 psi (666 bar) is used.

2. For pressure to be effective in reducing porosity, it has to be present when the metal is solidifying, and the metal cannot be pressurized before the end of the stroke. Thus, metal that solidifies before the end of the stroke can have large porosity – and this pre-solidification can come from a cold die, cold metal, a long fill time, a poor flow pattern, or perhaps low, local metal pressure – or a combination of these factors. These should all be reviewed in this situation. See NADCA information on shrink porosity for more specific information.

3. The factors that increase trapped air should be reduced — most of these are listed in the following information.

As mentioned, sometimes there are local areas in the casting that have low pressure during the critical time as the metal is solidifying. The low metal pressure occurs when the metal solidifies before the plunger applies pressure at the end of the stroke. This is possibly a temperature related cause, with either the die or the metal being too cold. It could also be caused by a dragging plunger that did not develop full pressure at the end; or because there was a shortage of metal (small biscuit in a cold chamber, or metal leaking by the plunger so it goes all the way to the bottom in a hot chamber machine). In some situations, it could be that the gate was frozen or partially frozen before the end of the stroke.

There could be other problems of course, such as a low metal pressure stemming from an incorrect calculation in matching the die to the machine, or a malfunctioning machine.

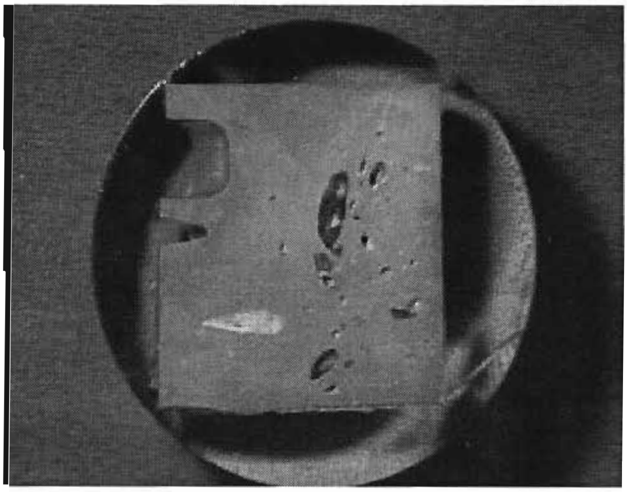

Figure 8: *A section with large but smooth-sided porosity shapes, along with some small rounded and smooth-sided bubbles. While these porosity bubbles look like trapped gas, it is more likely due mostly to low metal pressure in this area, along with some trapped gas. The large bubbles indicate that some trapped gas was present, but also that the metal pressure was very low.*

SOURCES OF GAS

Once the porosity is identified as most likely gas porosity, the next step is to determine the most probable source. There are four main sources of gas porosity in die castings.

1. TRAPPED AIR
2. TRAPPED STEAM
3. GAS FROM VAPORIZED LUBRICANT
4. HYDROGEN GAS

These will be discussed one at a time. It should be noted that the elimination of trapped gas, and particularly trapped air, becomes a case of making many small changes to eliminate all porosity sources. There often is no single magic bullet, and the problem solver should expect that reducing trapped gas porosity is a matter of careful control of many details.

TRAPPED AIR

In die casting, trapped air is usually the biggest porosity problem because of the very turbulent flow and the fast fill rate that is necessary in the process. If this problem could be eliminated, die casting would probably become the most prominent casting method, especially for smaller castings.

Trapped air should be considered as the first and most likely source of gas porosity, and sources of trapped air should be examined as the first step in troubleshooting gas porosity.

The first step is to start upstream at the beginning of metal flow. In the cold chamber process, this is the action of the metal in the sleeve, in the hot chamber process, this is the nozzle, sprue, and runner design.

Hot Chamber

Trapped air porosity comes mostly from bubbles trapped in the metal flow system. This is covered below in the runner design section. The problems cited in this section are the same for all types of metal flow, so the same comments will apply to hot and cold chamber.

The hot chamber system can be designed so there is a minimum of trapped gas, although it takes attention to small details that are often ignored. For most castings, ignoring the small details will not cause any noticeable problems, but for many castings, particularly the decorative castings, a small bubble or bubbling-out during painting or baking is a serious problem.

Cold Chamber

Air trapped in the shot sleeve can be very significant, consequently, the percent fill is an important process factor. For an example, in a 35% full sleeve where there is a total shot weight of 5 lbs or about 50 cubic inches of metal, 35% full means that there is 93 cubic inches of air at atmospheric pressure. At normal die casting with a final pressure of about 8,000 psi, and if all the air were trapped, there would be, for instance, 20 bubbles that are 0.167 inches in diameter somewhere in the metal. This is a lot of porosity. Trapping this much air in the casting is almost a certainty if the tool is made without vents.

Because of this, some process engineers will set percent fill as the single criteria for selecting the plunger size. However, it is a serious mistake to use sleeve fill percentage as the ONLY criteria for selecting shot sleeve size – to do so could mean an excessive fill time, an excessive metal pressure and extra flash, and a low gate velocity, which will give poorly filled castings, cold flow, flow porosity, and other problems. It is recommended that the plunger size be set by the process requirements of fill time, metal pressure maximums, die size, gate velocities, etc., then that adjustments to sleeve size that stay within these requirements be made. While this results in lower sleeve fill percentages, it results in much better castings.

Since the sleeve size is set by other requirements, a concerted effort is required to minimize the trapped air in the shot sleeve. Selecting the best shot profile (which includes the speed selection and the speed transition points) is the primary action to reduce trapped gas in the shot sleeve. The first step is to calculate the Critical Shot Speed (CSS). At this speed, the wave in the metal stays just in front of the plunger and all the air is forced out ahead of the metal and through the runner and the vents (or vacuum system). Speeds slower than the CSS allow the wave generated in front of the plunger to go faster than the plunger, which then reflects off the die surface and creates a large pocket of trapped air. Speeds too fast will cause the metal to "surf" or roll over.

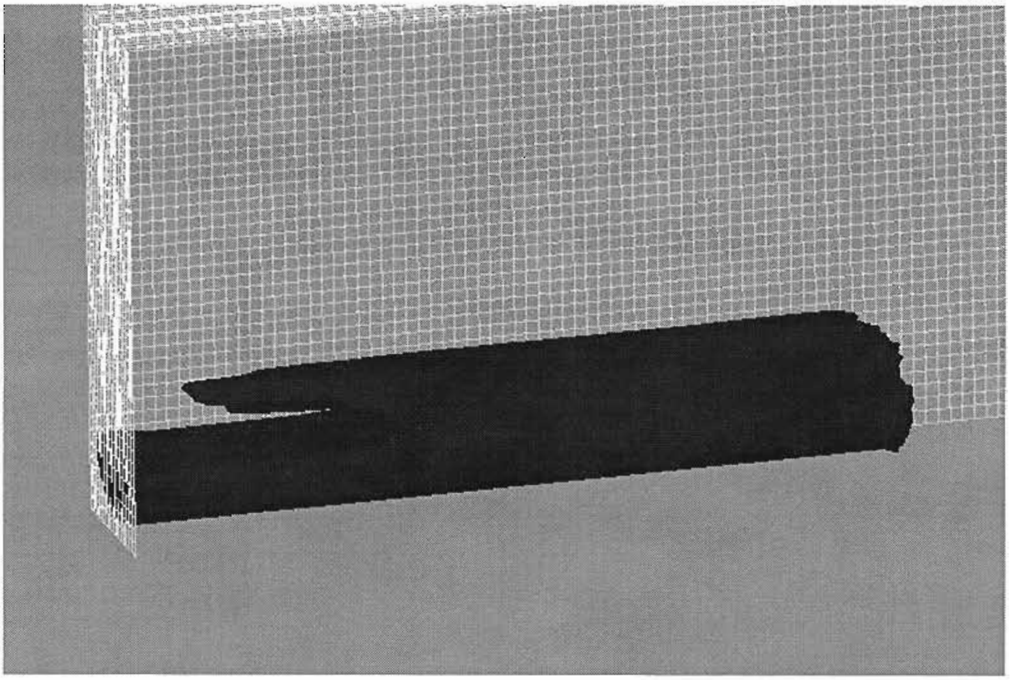

Figure 9: *"Surfing" wave generated by a speed well above the critical slow shot speed.*

This surfing effect is quite common in die casting, and can trap a large amount of air. The trapped air is dispersed into smaller bubbles, but these will still be large enough to be quite visible in most cases.

This "surfing" wave happens when the plunger is going too fast – faster than the CSS. The high speed may also be used to get a short fill time and a good-looking casting, which may cause the operator to choose between a good-looking casting with porosity and one that doesn't look as good, but that has lower porosity.

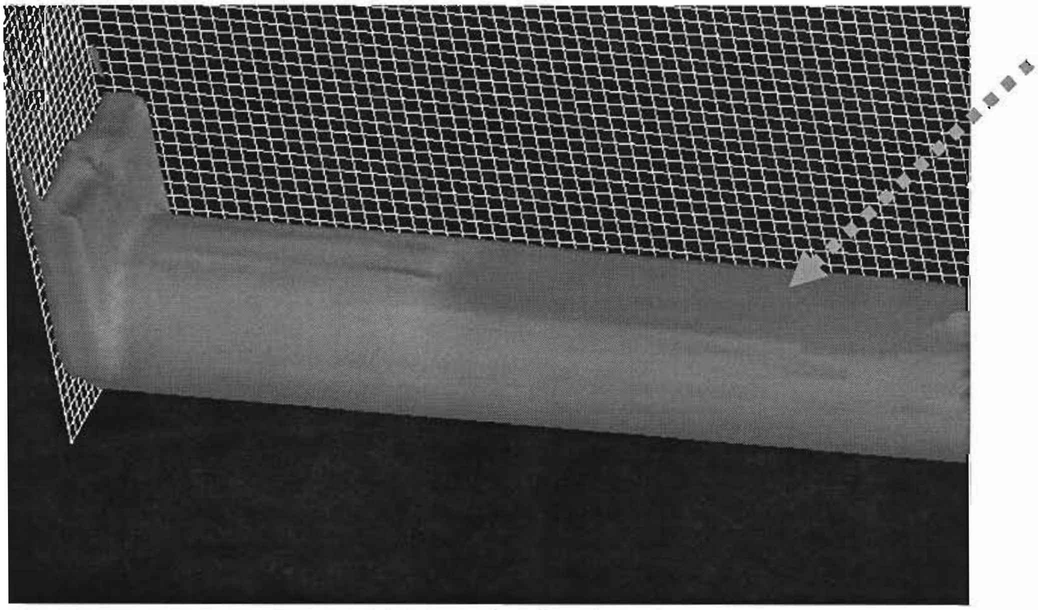

Figure 10: *Simulation model that shows the situation when the slow shot speed is too slow (about 7 ips below critical). The flat spot shown by the arrow is all air that will be trapped in the metal.*

When the slow shot speed is too slow, a wave is generated in front of the plunger that will move faster than the plunger. This wave moves forward, hits the die, and is reflected back to the plunger. A large air bubble is then trapped between the plunger and the reflected wave. The entrance to the runner is full, so there is no place the air can escape and it is all trapped in the metal.

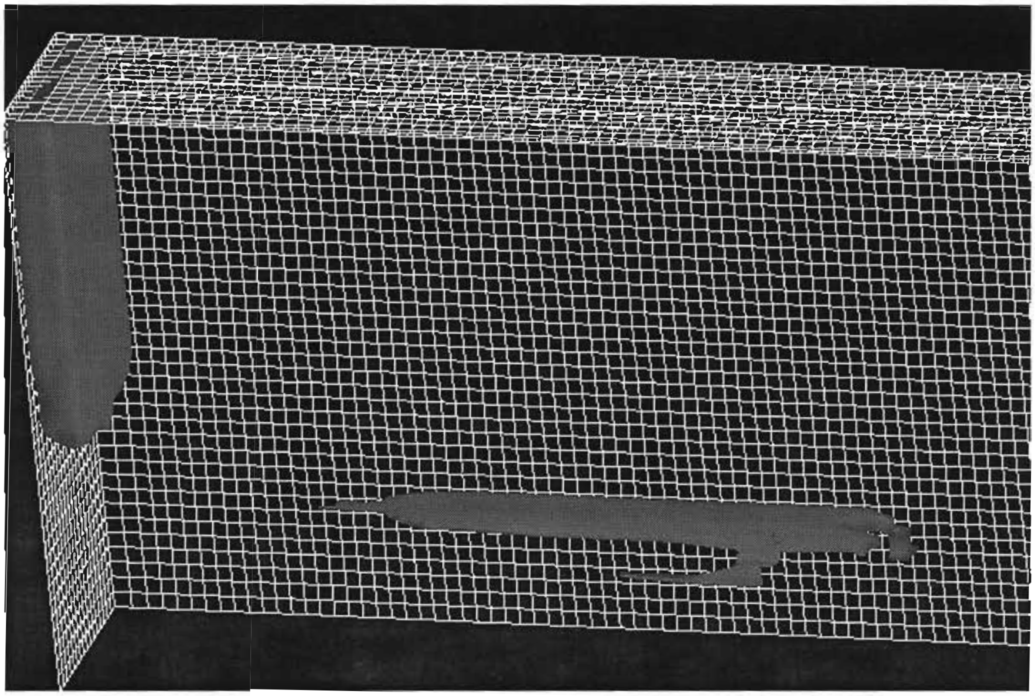

Figure 11: *The red areas are the air spaces for the situation shown above. The one on the lower right is trapped in the sleeve and will be broken up into smaller bubbles and passed up the runner into the casting as porosity.*

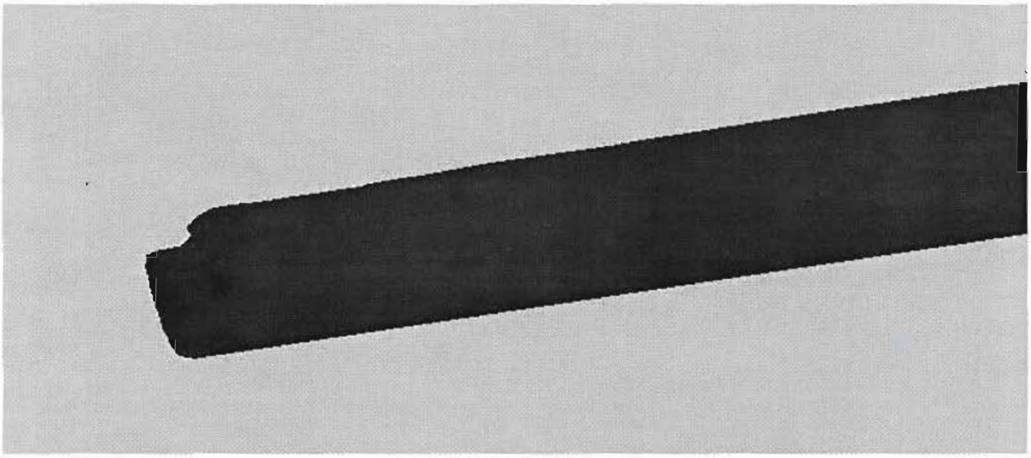

Figure 12: *Plunger speed at close to critical slow shot speed, with the accelerations to slow shot and to fast shot set so the air is pushed out ahead of the metal - where it can exit through the vents or vacuum system.*

Calculating and using the CSS are important activities that can influence the amount of trapped air.

To calculate the critical slow shot speed (C_{ss}), use the formula shown below.

$$C_{ss} = K \text{ x } (\text{Dia}).5 \text{ x } (\{ 100 - \% \text{ fill}\} / 100)$$

Where: Css = Critical slow shot speed
K = A constant, 22.8 in/sec, or 3.634 m/sec
Dia = Plunger diameter
% fill = Percent fill of the shot sleeve, expressed as a whole number

The critical speed calculation is not considered accurate below about 50% fill because the wave becomes more unstable. In that event, experimentation is used to find the best settings. Somehow, the best settings must be determined, so if the experimental work is not done carefully the optimum solution may not be found.

Some of the other settings that should be reviewed include:
(The asterisked items are usually the most influential.)

- Ladle pour rate
- Delay before shooting timer*
- Pour hole speed (if used)*
- Pour hole speed to slow shot speed transition point (if used)
- Slow shot speed*
- Slow shot to fast shot transition point*

All of these settings should be considered when conducting the experimentation; all are relatively easy to set up and respond well to the use of Design of Experiment (DOE) techniques. The number of variables is limited, and the interactions are fairly limited (unlike other casting DOE problems). The first choice may be to run a full factorial using slow shot speeds and changeover points as variables.

A typical problem solving effort would involve calculating the CSS and setting it on the machine, then setting the fast shot start point at the point where the sleeve is full. The slow shot start should be set just past the pour hole (if a pour hole speed is used). Then a DOE would use a high and low setting of the slow shot start and end points, a speed just below and one just at the CSS. Continued experimentation would try to establish the optimum settings, and may include another variable, such as the setting of the delay before shooting timer.

It should be mentioned that extensive use of DOEs in the shot end area is the most common method of reducing gas porosity in some overseas facilities.

It is better if the development of the optimum shot profile, whether done by experimentation or simulation, is done by the process engineer as a formal part of the process development, not in production later. It should be noted that running DOEs takes some skill, and also takes up a bit of production time. Simulation can be done ahead of time, and can be done faster than the actual experimentation methods. The pictures used here come from simulation results.

Not emphasized here, because it is difficult to change on most machines, is the acceleration rate. The most important acceleration is that which goes from rest (or from pour hole speed) to the critical slow shot speed (see the NADCA sponsored The Ohio State University Trasactions paper "Optimal Slow Shot Velocity Profiles for Cold Chamber Die Casting). As a result of the OSU work, it is apparent that this factor is very important (along with CSS) in reducing the trapped air. However, since the acceleration is not adjustable on most machines (valve replacements are needed on most machines), it is not usually adjusted.

The effect of rapid acceleration is below, using simulation results.

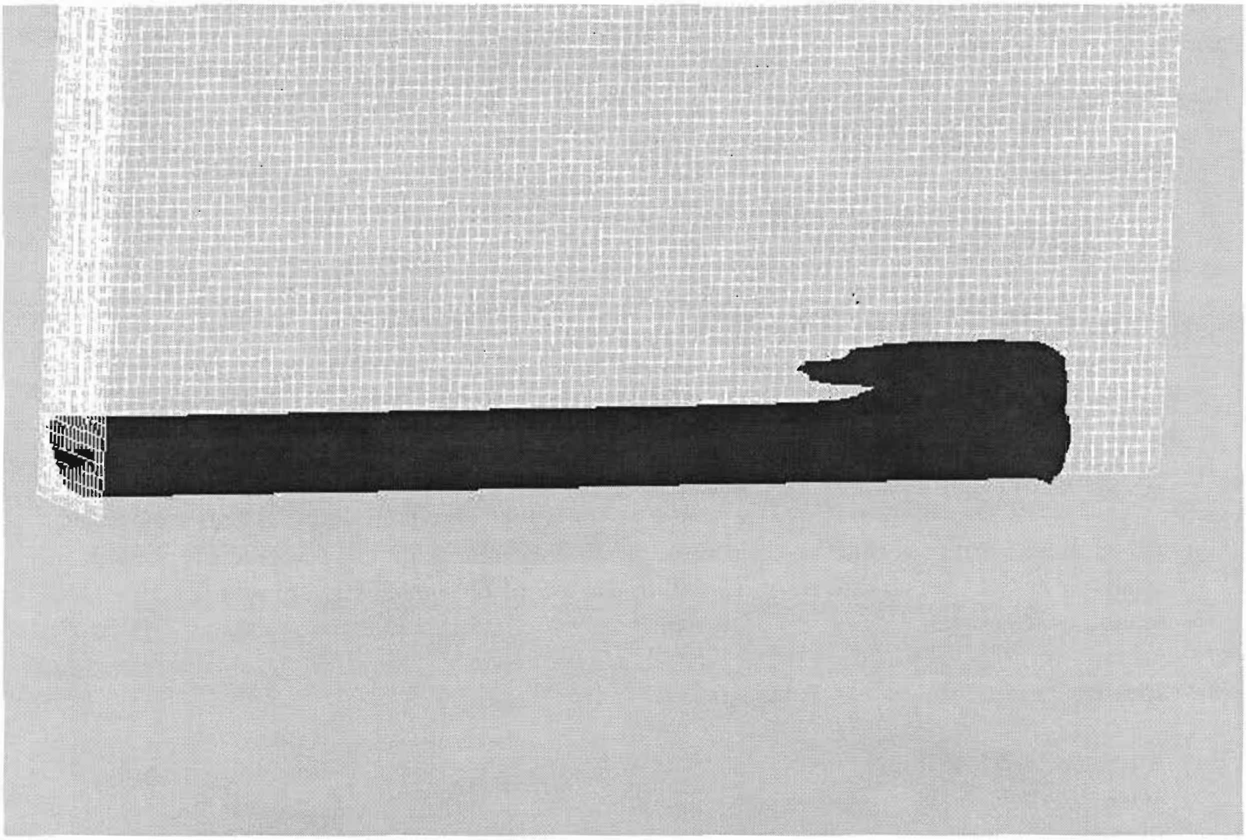

Figure 13: *Early surfing wave from a quick acceleration. The plunger started out slow using a slow pour hole speed, then was jumped to the CSS with a very fast acceleration (this is normal for many machines). The "surfing" effect would have been worse if a higher final speed was used.*

The OSU work shows that the best profile involves a constant acceleration to CSS, then maintaining the CSS until it is deemed time to go to fast shot speed. Adding the valving to control the acceleration to slow shot speed may not be difficult or expensive (depending on the machine), and it is certainly worth exploring if trapped gas porosity is a critical factor for a particular machine.

VENTING SYSTEM and VACUUM SYSTEM

All the effort listed above is aimed at trying to force the air out of the shot sleeve ahead of the plunger, and this approach depends on having a place for the air to go. This means there must be a venting or a vacuum system. If there is not, then none of the effort listed above is worth any time investment because all the air in the sleeve will be trapped in the casting.

The first step is to size the vents. The vent area can be calculated based on the idea that the air has to leave the cavity at the same flow rate as the flow rate of the metal entering the cavity. The incoming metal flow rate is Q, which can be calculated a number of ways, but it usually is calculated from the plunger speed times the plunger area. The desirable minimum area of the vents can be found from:

Area of vents = Q/VMAX

Where:

Area of vents = The area of all the vents on the whole die
Q = Flow rate of the metal into the cavity
VMAX = Maximum air velocity in the vents, which is suggested to be: 8000 ips or 200 m/sec

The maximum air velocity in the vents is taken as 8000 ips (200 m/sec), which is about 70% of the speed of sound at standard conditions. This is judged to be the maximum practical speed in the vents – above that speed the back pressure builds up and air flow does not increase because of the shock wave affect. This formula will often result in a vent area of about 20% to 25% of the gate area, assuming a design gate velocity of about 1600 ips to 2000 ips.

The next step is getting the vents in the best location. Most vents should be located at the last points to fill, and finding these locations can be done with experience, using the blind locations at the end of the casting; or with a simulation. Predicting the last points to fill is one of the most valuable uses of flow modeling and simulation. Also, with simulation, modifications can be made before making the die. Usually several vents are needed, and they should be located at any dead end space — or the flow direction should be changed so the pockets are eliminated.

Vent location is absolutely critical if porosity is a major concern, so the venting should take precedence over other factors. For example, it is often desirable to rotate the die to allow space for vents, even though it takes more die steel. The die caster should control this portion of the die design if long-term costs for porosity are to be controlled.

Vents must go to the edge of the die to be effective. Vents usually are about .004 to .006 deep for zinc and magnesium, and .005 to .008 deep for aluminum. The vents must be polished to allow any metal in the vents to come out with the shot. Draft is needed on the sides (even if they are only .005 inches deep) to keep any metal from sticking. It is always tempting to the operator to leave metal hanging in the vents if it is hard to clean out – after all, the casting does not look any different.

Venting off an overflow is a good idea, but not necessary. Overflows and vents have very different functions, and overflows are not necessary for a vent to function.

Using a "Z" shaped vent can allow the vent to be deeper (up to about .03 inches in some cases), and will allow a lot of venting in small areas. The z shape looks like the sketch below.

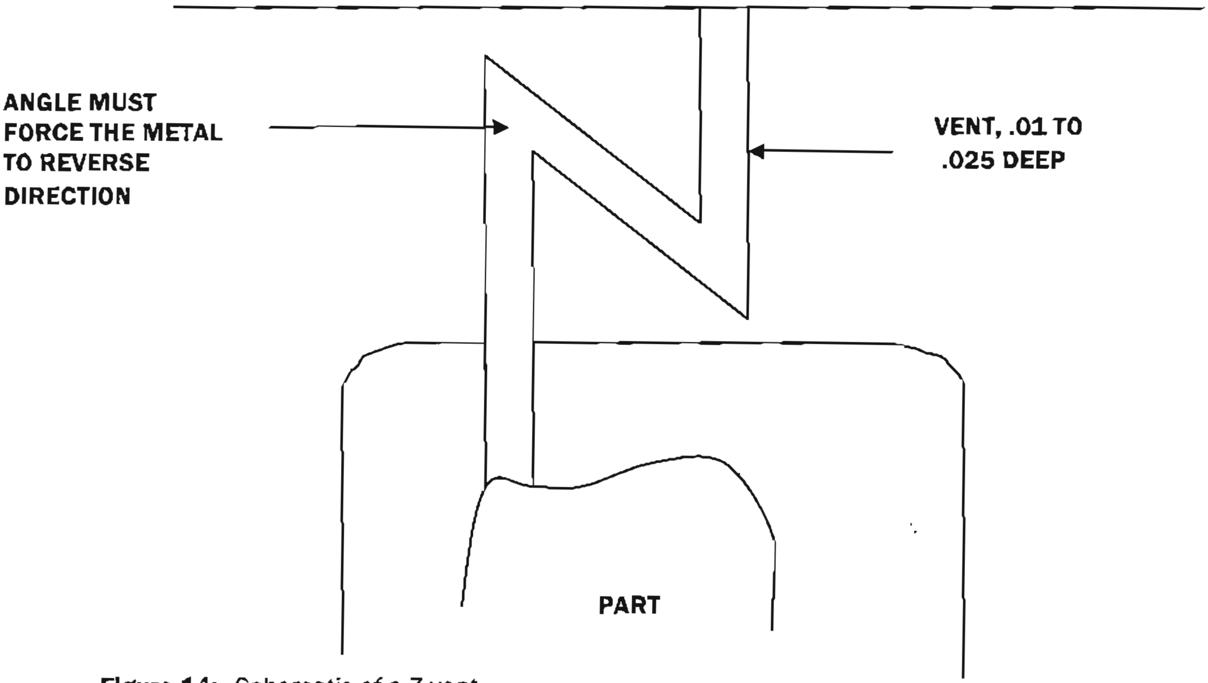

Figure 14: *Schematic of a Z vent.*

The vacuum system is now a regular production tool in most die casting shops, and vacuum systems are either those with a valve or those with "chill blocks." The chill block system is the most popular, and is the lowest cost with the least maintenance, but it cannot (at least theoretically) reach the lower vacuum levels achieved by the valve actuated systems. Homemade systems using a chill block are easy to build and probably constitute the majority of the vacuum systems in use.

One consideration for the use of vacuum systems is that a large part of the air that could be trapped in the system can come from the shot sleeve, and reducing this volume with a vacuum system is difficult because the vacuum cannot start to work until the plunger seals off the pour hole. Thus, there is only about 0.5 to 0.9 seconds available to evacuate the air in the whole cavity and the shot chamber –this is a very short time to expect many vacuum designs to do their job.

Sometimes a very slow plunger speed is advocated in order to allow time for the vacuum system to work, however, recent work for NADCA at The Ohio State University shows that the thickness of the chilled skin in the shot sleeve caused by longer dwell times will cause some extra contribution to cold.

Most systems will generate a partial vacuum during the plunger movement, so the most productive effort for the engineer is to provide a larger and less restrictive vacuum channel, and to make sure flow paths for the vacuum system are large enough to maintain a very low pressure (in spite of any leaks). This leads to a system with large pumps, a large vacuum tank, large pipes and large vacuum channels.

Thus, part of getting the air out and then the porosity out of a casting involves the engineering of the vacuum system, including channel sizes, the proper plunger speed profile, and the proper vacuum equipment.

A compromise needs to be met between the CSS settings and allowing time for the vacuum system to work. If an effective vacuum system is installed, it is probably better to use slower shot speeds (slower than the CSS) in order to allow the vacuum time to work – although this needs to be examined carefully for each job.

The location of the vacuum channel connections should be at the last points to fill, which are best defined by flow simulation. The NADCA software called CastView is very reasonable in price; very, very fast to run, and does an excellent job in defining the last points to fill. Other simulation programs can also define these points. If simulation is not available, another technique (but more expensive) is to not put in the vents or overflows until after the first sampling. Several short shots are then made during the sampling to get the last points to fill.

RUNNER AND GATE DESIGN

The last area of concern for reducing the trapped air is the runner. Here, the best results come from good design, one that follows the NADCA rules. Basically, these rules require that the runner be smooth, rounded, and smoothly decreasing in area from the shot sleeve or sprue to the gate. The largest percentage area reduction should occur at the gate, where an area reduction of from 10% to 40% is typical.

By itself, the runner may not introduce a lot of porosity, consequently, a runner design that breaks the rules may still work. However, there is no question that a poor runner design introduces trapped air — the only issue is how much porosity is caused by the poor runner design, and whether it ends up in an acceptable location or not. Thus, it is always worth the effort to properly design the runner using the NADCA calculation methods.

Trapped air in the runner comes from any space where the metal flow goes from a small space to a large one, causing the flow to expand rapidly, which then causes the metal to pull away from the wall of the die. This leaves an area where turbulence develops and some air is trapped. There should be NO sharp directional changes, die mismatch, or ejector pins that protrude into the runner – at least if all possible trapped gas is to be avoided.

A typical issue is the shape of the gate. The NADCA design method requires the gate to have an ever decreasing area from the runner to the gate entrance. If it does not, the metal can pull away from the side and generate trapped air. This will happen with a straight sided gate design (this is a fan gate with all sides straight). If the NADCA rules are followed, one side of a fan gate must be curved – either the sides or the top – so as to provide a smoothly reducing area for the metal as it flows from the runner to the gate.

A fan gate of the straight sided design does not have even area reduction. This causes the metal to pull away from the walls of the gate shape, which will introduce bubbles into the casting. This is shown in figure 15.

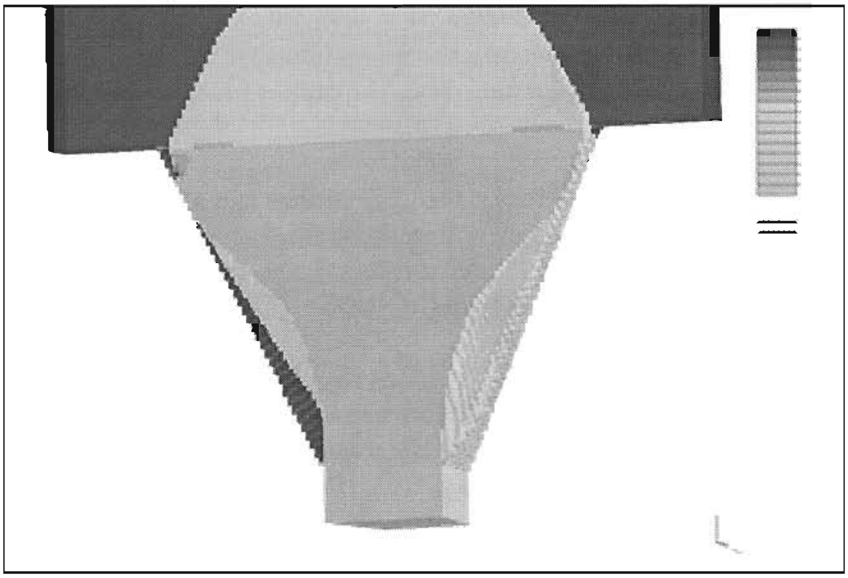

Figure 15: *A simulation showing how the metal flow starts into the cavity and the way the metal will pull away from the walls of the runner if a fan gate with all straight sides is used. The pockets of air will form in these areas, which will be pulled into the cavity.*

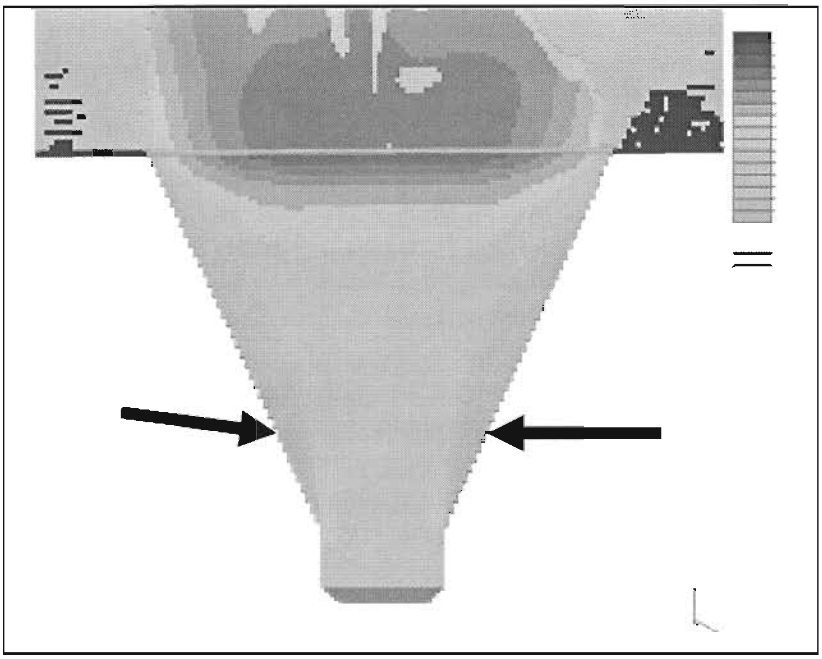

Figure 16: *Metal flow in a flat fan. Note that at the edges of the gate, air bubbles are being fed along the path shown with the arrows. The blue areas with the arrows are the low velocity areas that contain trapped air.*

The bubbles from the runner system may stay in one location, or they can move randomly if the flow parameters change a little each shot. Troubleshooters struggling to fix nagging porosity problems would do well to consider these issues. Long or short ejector pins, or any cause of turbulence will cause some porosity – the only issue is whether it is enough porosity to cause a problem.

The atomized flow condition that is used in typical die casting will tend to break up any air bubbles in the metal into smaller bubbles, and these may get reduced in size enough so they are not easily visible. Thus, higher gate velocities tend to mask porosity generated in the sleeve or the runner system – and this may be useful in some situations, but this is generally not a real effective way to mask porosity.

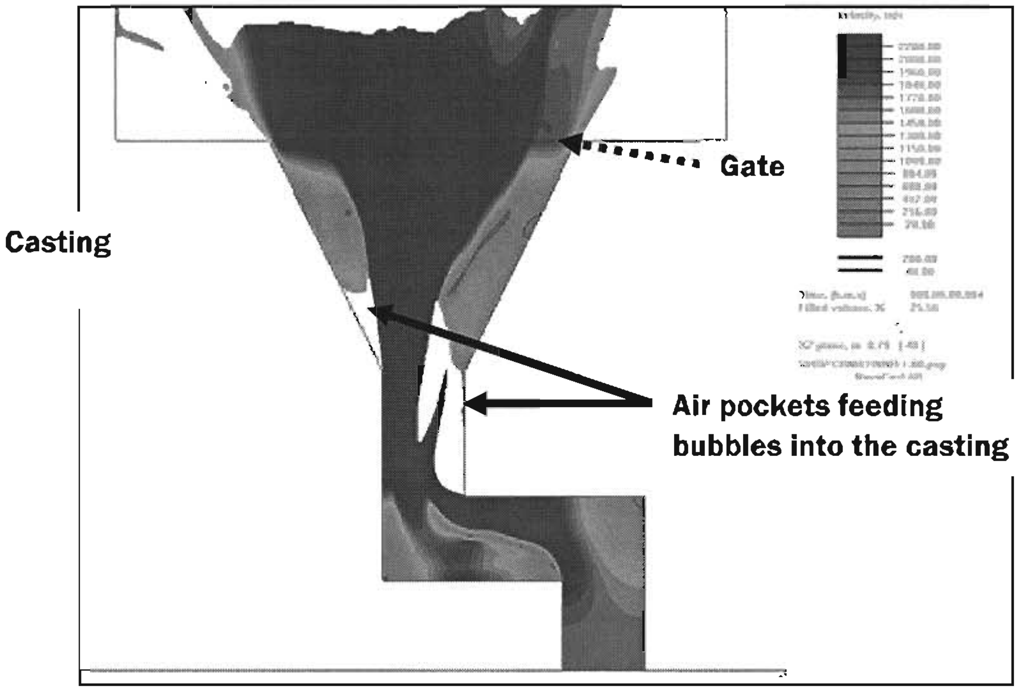

Figure 17: *Section taken through a runner system with square corners and a poorly designed gate. (Novacast simulation).*

The figure shows a section that was taken through a runner system with square corners and a fan type gate that was not made to NADCA recommendations. (It has no curved sides, each side of the fan was straight.) The red sections are high velocities, running from 1800 ips to 3500 ips. The blue areas are at very low velocities. As can be seen, the square corners in the runner distort the flow and cause jetting with some very high velocities, and this jetting carries from the square corner into the gate. At the gate, the flow spreads out (dotted arrow), but flow is uneven across the gate. In the runner and the start of the gate, there are large air pockets that will feed trapped air bubbles into the casting (solid arrows).

STEAM AND GAS FROM VAPORIZED LUBRICANT

The next largest source of gas is from steam and/or vapor generated by burned or heated die lubricant. Most die lubricants are water based with about 95% to 99% of the spray mixture being water, so much of the gas from vaporized lubricant comes from water. Also, for many dies, this type of die spray is the most available and the easiest method of getting some temperature control for the die. The aspect of temperature control becomes more important than using the water as a way to get the lubricant to the die surface. Thus, an effort to get better temperature control often means that there is a lot of lubricant (and consequently, water) used on the die (especially in aluminum).

The water causes a problem because a small drop of water will expand to a bubble of steam approximately 1500 times the size of the original water drop — this is a lot of gas. Since this steam bubble is not formed until the drop is surrounded by liquid metal, it becomes immediately immersed in the molten metal and there is no chance to force the gas ahead of the metal and out the vents or to extract it with the vacuum system. Thus, the methods used for trapped air, such as adding vents or overflows, is not going to be a big help.

Some clues are available to detect whether moisture is the problem for a given casting. The type of porosity that comes from moisture may appear shiny or it may appear dark if it comes from vapor from standing die lubricants – especially plunger lubricants.

Apart from the appearance clues, which are not conclusive, it can be hard to pinpoint the source of gas porosity. However, there are some other ways to develop clues. One is to run several shots without lubricant – usually several shots can be made without sticking (this should be done carefully under the supervision of an experienced process engineer). These shots can be evaluated and compared with average production casting quality. (Often the engineer or trouble shooter may not have access to samples that would be considered typical, and may have to develop samples and basic data as a starting point. These are invaluable for use as a check on any improvement effort, and are well worth the effort to develop.)

Another clue may come from the location and size of the porosity. If, for example, a drop or two of spray (or water from a cooling line) is always located in a certain spot, these drops may be converted into a number of small bubbles that will appear grouped, consistently in about the same location. A group of smooth bubbles consistently gathered in one location is often a symptom of water on the die – look for a die location that traps over-spray or that may have a water leak. For example, if the porosity comes from trapped air in the shot sleeve, the porosity tends to be more broken up and random in location.

Sometimes a leak from a cooling line is through a small and unnoticeable crack in the die and this crack is not opened up until the machine clamps the die. A way to test for this is to shut the die with the water on, but do not make a shot. After a short hold time, open the die and check for wet spots.

The plunger lubricant is a frequent source of gas porosity, and this will be truer if the lubricant is applied ahead of the plunger. Certainly, the use of plunger lubricant is needed, the big problem is not that it is used, but that it is not controlled. For example, an operator may try to nurse a bad tip to the end of the shift and dramatically increase the amount of plunger lubricant applied. In many shops, the amount applied is determined from shot to shot by the operator. This results in a varying amount being applied, which can be a real porosity problem. In general, the amount applied should be held to a bare minimum. Operating practices should dictate that a plunger be changed as soon as problems are noticed, and that plunger tips or sleeves not be nursed for several shifts with a lot of lubricant.

The lubricant should also be matched to the die temperature so there is the proper amount of evaporation and a minimum of excess material left on the die. The proper die lubricant should be chosen in conjunction with a knowledgeable technician from the lubricant company, and the technician should know of any stringent porosity requirements.

Before deciding to use a lot of over-spray on a portion of the die as a way to control temperature, the engineer should consider the probability of increased gas porosity. Another consideration is that over-spray is one of the major factors affecting die life.

Probably the single most important prevention factor is making sure the die is dry when it closes. There should be no visible moisture on the die as it closes. While a wet die may be a common practice for some dies and the product made using this procedure can be acceptable, there is definitely some added gas porosity – but in some cases, it is not noticed.

The use of strong air blow-off is very important for overall porosity control, and it always needs the process engineer's attention. Again, this is a process discipline that is very important for maintaining good gas porosity control. The blow-off of many sprayers is simply not adequate to clear the big drops of moisture off the die, and sometimes they need to be augmented with extra pressure or bigger size pipes.

Attention is needed in the die design to eliminate pockets or areas (such as behind slides) where water can accumulate, especially during start-up when the die steel may be colder.

GAS FROM HYDROGEN

Gas porosity from hydrogen gas is always a factor in handling molten aluminum, and it is a major source of trapped gas in other aluminum casting methods. However, this is not always the case in die casting.

First, the solubility of hydrogen in die casting alloys is less than about .68 cc/gm (at liquidus). Die casters tend to use casting temperatures not far above liquidus, and the solubility of hydrogen is reduced by about three orders of magnitude as the temperature goes below about 1250°F – consequently there tends to be much less gas available in the melt for a typical die casting situation.

Studies at The Ohio State University have shown that the typical gas content of a sampling of aluminum die castings ranged from about 4 to 30 cc/100gm, and a range of about 10 to 15 cc/100gm is typical for many die castings. (The mean was 12.9 cc/100g.) Thus, for the average casting in this study, the contribution of hydrogen gas is small – about 5% to 10% - when compared to the total gas content. (The samples for these studies were taken from many different plants, and were different sizes and run on many different types of machines, so this is considered a typical value for die casting.)

While there is likely to be a contribution to the gas porosity from hydrogen, it is small enough that the engineer or trouble shooter should not focus the majority of effort on the reduction of hydrogen. It is likely to be a small contribution when compared to the trapped gas that comes from the other sources in the process. Thus, the actions advocated here should be the first step in correcting a typical die casting gas porosity problem.

The study did show that there are some die castings made with a gas content in the range of 3 to 5 cc/gm, which indicates that it is very possible to get the rest of the trapped gas sources under control – after the other factors are under control, the hydrogen gas can become a more significant factor.

Methods of controlling hydrogen gas are well known in the casting industry. The most common, and one that should be used in all plants, is to use fluxing and degassing procedures. These procedures also take out some of the oxide material that can cause other problems.

CONCLUSION

To summarize, the control of gas porosity requires a planned effort that requires good disciplined process management and good engineering. As can be seen from the description of the causes, the effort will need to focus on many little things, and on managing the process so there is good consistency. Success will come from accuracy and carefulness in all of the details.

The effort for minimizing trapped air is especially important. The proper use of vacuum, plus paying attention to details in the plunger speed settings, running DOEs on the important variables, taking advantage of simulation, and using good design procedures for the runner, gate and vacuum system will take care of most problems.

Trapped vapor from steam or die lubricants is also managed by engineering the system carefully, then using good process control and discipline to maintain good settings.

It has been demonstrated that when applied correctly, these procedures can reduce the gas content to the 5 cc/gm range or below. This can result in castings that are very competitive with other casting methods or competing processes and expand the die caster's market and profitability.

Appendix

To assist the reader in visualizing certain condition, simulations for the conditions listed below can be viewed by accessing the respective video files online at:
www.diecasting.org/publications/516

Simulation of air entrapment in a shot sleeve during the slow shot portion of the injection.

Simulation of air entrapment in a shot sleeve caused by early acceleration (fast shot transition point set too soon).

Simulation of air entrapment in a shot sleeve caused by the slow shot speed being set too low.

Simulation showing an acceptable wave formation in a shot sleeve as a result of an idea slow shot speed.

Simulation showing the impact of sharp corners in a runner system on air entrapment.

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