Simulating Porosity in Ductile Iron Castings

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Ductile, or nodular, cast iron components have many advantageous characteristics which combine high toughness, increased ductility, high strength, fatigue and wear resistance. Nodular cast iron is created through an alloying process (usually with Mg) where nucleation favors the formation of graphite nodules instead of flakes of grey iron, thereby giving the material increased ductility and superior elongation properties. Some typical automotive ductile iron parts include steering knuckles, exhaust manifolds, brake calipers, camshafts, clutch drums, brake cylinders, connecting rods etc.

During casting, unlike most cast alloys, ductile iron does not simply contract as the metal cools and solidifies. In the liquid state the volume change is quite linear and predictable but as the metal begins to solidify, ductile irons show a considerable amount of expansion due to graphite precipitation. This effect can allow experienced foundrymen to make use of riserless methods.

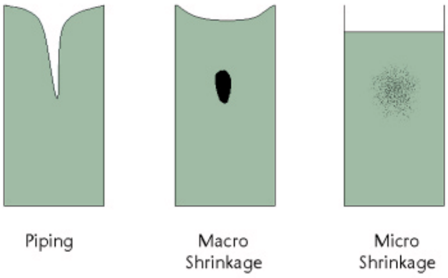


Figure 1: Illustrated images showing the different forms of shrinkage porosity.

Introduction to Porosity

Shrinkage porosity, as shown in Figure 1, can be characterised by the following:

a) Pipe shrinkage, including surface sinks, occurs early during solidification when the liquid metal on the surface of the casting, exposed to the atmosphere, is under a depression due to the contraction of the solidifying metal on the inside. The metal is then pushed downwards (or inwards) by atmospheric pressure forming a pipe, or sink, which is visible on the surface of the casting.

b) Macro shrinkage occurs when the liquid is surrounded by enough solid material which is strong enough to resist the depression of the contracting liquid. Usually the size of the pores is greater than 3mm. These defects are internal and can generally be prevented by optimal pouring temperature, riser positioning and size.

During solidification the expansion of the metal due to graphite expansion can cause liquid to be pushed back into the gating system resulting in problems with porosity during subsequent solidification.

c) Micro shrinkage occurs late during solidification and is formed between the solidifying dendrites. Usually the amount of micro shrinkage is influenced by the cooling rate, pressure and alloy freezing range.

The casting of nodular iron is interesting because the formation of the graphite nodules during solidification can lead to a total net volume expansion, as shown in Figure 2. However, contrary to what might be expected, micro-porosity can nevertheless form. The expansion of the solid skeleton during solidification should be taken into account to explain this phenomenon. Similar to a sponge when it expands in water, a suction of the liquid occurs in between the interstices of the sponge leading to a pressure drop, which in the case of solidification is responsible for micro-porosity.

However, if the outer surfaces of the casting are prevented from expanding then an increasing pressure on the inside can help to feed this micro-shrinkage. Good gating design can help to take advantage of this phenomenon.

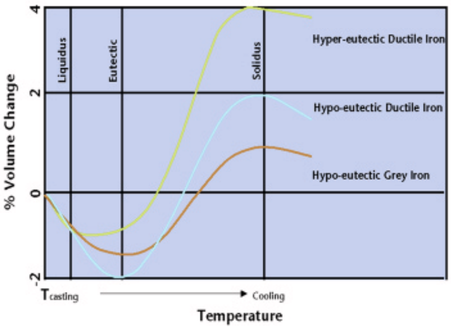
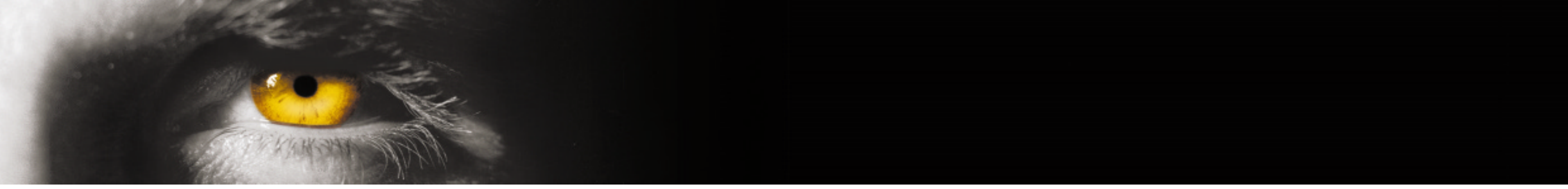


Figure 2: Volume change during solidification for hyper-eutectic, hypo-eutectic ductile and grey cast iron. Ref. http://www.ductile.org/magazine/2001_3/elidavid.htm



Simulating porosity

Predicting the behaviour of the metal during solidification is not trivial as one needs to consider the different modes of shrinkage as well as trace the evolution of the liquid metal free surface. One has to distinguish between how much volume change is used for macro shrinkage and how much is used for micro shrinkage.

The amount of shrinkage will depend on the following:

- thermal cooling conditions
- the alloy content
- the casting temperature
- the amount of graphite expansion occurring during solidification.

Example

The example shown in Figures 3 of a casting without riser sleeves was simulated to illustrate the influence of graphite expansion on the porosity results.

The porosity results are shown in Figure 4 & 5. When taking graphite expansion into account, as shown in Figure 4, the porosity is considerably lower than when not considering expansion, as shown in Figure 5. In the later results there is also the presence of pipe shrinkage.

Conclusion

Simulating ductile iron castings using ProCAST can help to understand the solidification behaviour and determine the effect of graphite expansion on porosity.

Optimal gating design can then be determined to help take advantage of this expansion effect in ductile iron castings.

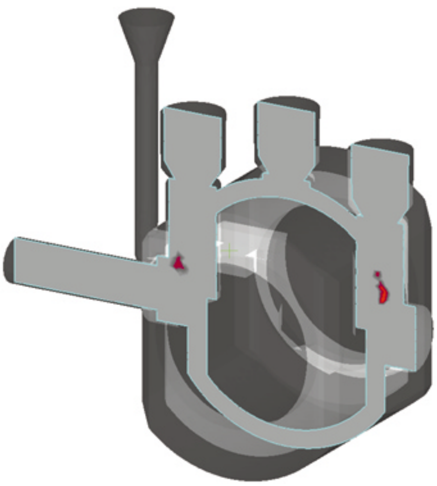


Figure 4: Cross-section contour plot of porosity where red indicates macro porosity. Ductile cast iron simulation when considering the graphite expansion. Results performed using ProCAST

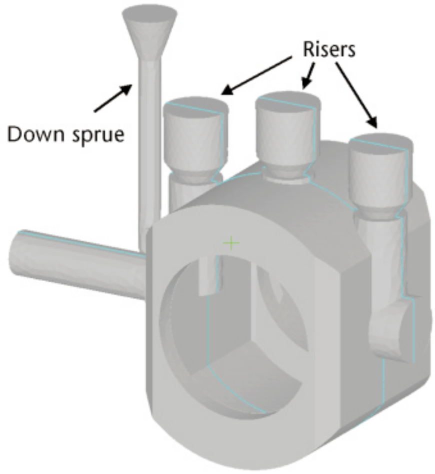


Figure 3: Geometry of casting indicating the risers, down sprue and blue line indicating the cross-sectional cuts in Figure 5 & 6.

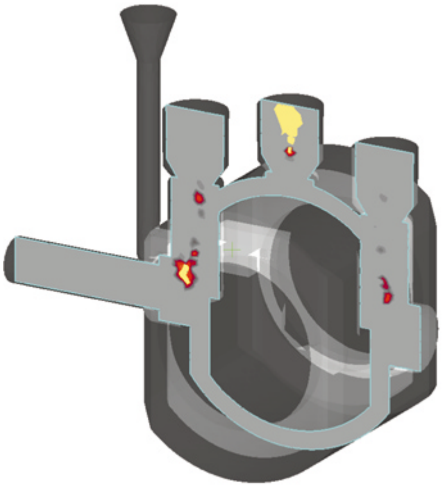


Figure 5: Cross-section contour plot of porosity where red indicates macro porosity and yellow indicates 100% vacant region. Ductile cast iron simulation when not considering the graphite expansion. Results performed using ProCAST.

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