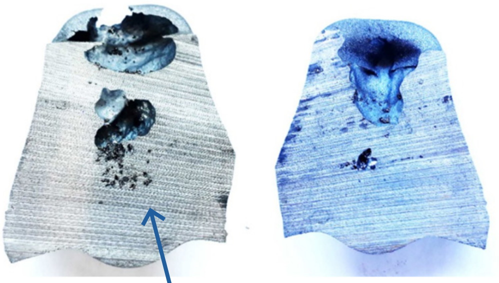
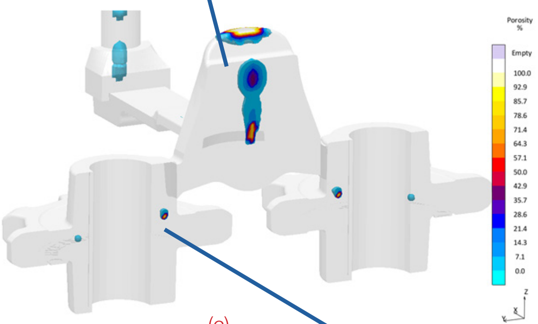
# SHRINKAGE POROSITY



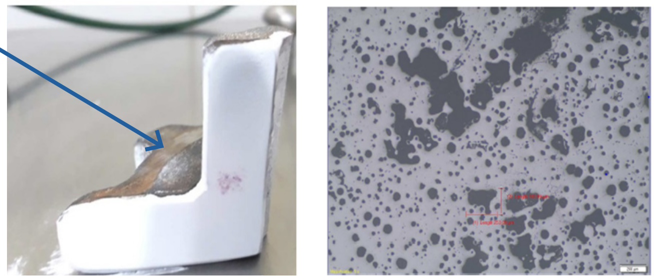
(a)



(c)

## Description:

Shrinkage porosities are voids resulting from volume contraction during solidification and occur by inadequate feeding. Shrinkage porosity in cast iron is usually classified as macroshrinkage (primary shrinkage) and microshrinkage porosities (secondary porosities), their origin is the same, but they show differences in morphology and related to the solidification stage in which they were formed . Primary shrinkage occurs in the early stages of solidification with a low solid fraction in the different areas of the casting and is normally compensated by the feeders. On the other hand, secondary shrinkage occurs during the last stage of solidification, when most of the liquid flow is already interrupted and only graphite expansion can compensate for it. Related to the different stages of solidification during which they occur, primary shrinkage generally leads to large (Figure 1 a), smooth voids, while secondary shrinkage exhibits dendritic morphologies (Figure 1 b) (01).



(b)

▲ Figure 1(a): Macroshrinkage porosities in the feeders; (b) Microshrinkage porosities showing a dendritic morphology on their internal surfaces; (c) Porosity results prediction in a ductile iron casting

## Simulation Interpretation:

Fraction liquid and temperature results show the solidification path and when the portion of liquid is isolated. Hotspot and porosity (Figure 1 c) results show the location, volume and intensity of the shrinkage porosity.

To be able to identify if the porosity is a macro or microshinkage porosity is necessary to analyse the porosity results progressively and identify together with the fraction liquid which stage of the solidification the porosity is being created.

## Possible Root Causes:

Macroshrinkage porosities:

- Insufficient feeding due to isolated areas of liquid metal
- Small modulus of the feeder neck
- Undersized or imporperly shaped feeders
- High pouring temperature

Microshrinkage porosities:

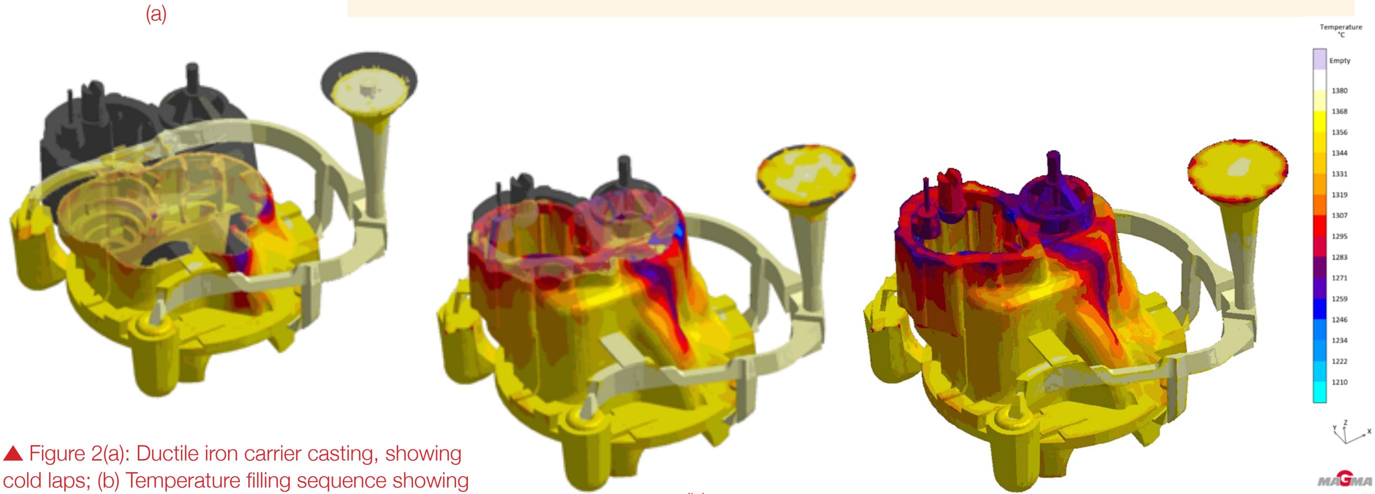
- Carbon equivalent composition
- Lack of inoculation or low inoculant efficiency
- Weak mold or low sand compaction in specific regions of the mold
- Alloy elements segregation (Ex.: Mo, Cr)

# COLD SHUT/COLD LAP/MISRUN


(a)

## Description:

Cold shut, cold laps and misruns are surface defects which have similar root causes, but change in the morphology. Cold shut can be defined as a discontinuity that appears on the surface of cast metal as a result of two streams of liquid meeting and failing to unite (01). This defect is visible to the naked eye and often results in rejecting the casting, as it creates a weak spot. Cold laps are usually wrinkles marks on the surface caused by too low casting temperature as shown in the Figures 2 (a). Misruns occur when the liquid metal is too cold to flow or the air cannot be extracted at the extremities of the mold cavity before freezing and solidifying. The liquid metal does not completely fill the mold cavity.




▲ Figure 2(a): Ductile iron carrier casting, showing cold laps; (b) Temperature filling sequence showing locations with lower temperatures and cold lap tendencies

(b)

## Simulation Interpretation:

A detailed analysis of the cavity filling temperature (Figure 2 (b)) and velocity behaviour allows to visualize the flow pattern and in which temperatures the flow streams meet. Filling temperature criteria results show at which temperature of the molten melt reaches a specific region of the mold. Low velocities and high air pressures in flow front or at the end of the filling can show similar defect characteristics even with relatively high temperatures.

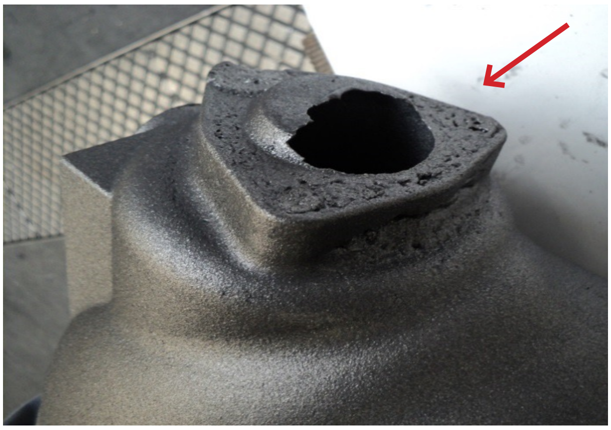
## Possible Root Causes:

- Low pouring temperatures
- Interrupted pouring times
- Long flow distance with low velocities
- Non optimized gate positions - to minimize narrow cross-paths and ensure short flow paths
- Low height difference between the top level of melts in the pouring cups when filling the molds and the top area of filling cavities.
- Filling failure due to internal gas, which cannot be evacuated quickly to open air
- Low sand permeability
- High viscosity of the melt due to alloying elements such as aluminium, phosphorus etc. (01,02)

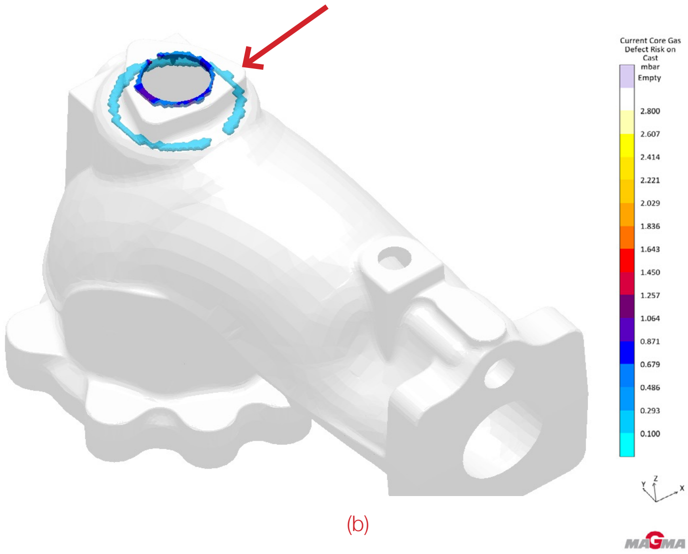
# CORE GAS POROSITY

## Description:

Core gas porosity is also called blowholes, where the cavities are characterised as relatively large bubbles with smooth surface.They are formed within the casting due to residual gas generated from the thermal degradation of the organic binders and, where applicable, of other volatile components. When using inorganic binder systems, gas formation primarily takes place due to the evaporation of residual moisture. The formed bubble is trapped in the casting and unable to escape during filling/solidification due to insufficient venting system. Usually this kind of defect is located adjacent to the core, just below or at the casting surface as shown in Figures 3 (a) and (b).



(a)




(b)

▲ Figure 3(a): Core gas porosity in the casting surface; (b) Current Core Gas Defect Risk on Cast result showing the location of the core gas porosities

## Simulation Interpretation:

The result of Current Core Gas Defect Risk on Cast (Figure 3 (b) shows where the gas was released from the core to the cast and depending on the temperature of the molten melt this will be the most likely location for the porosity. Additionally there different results available to analyse the the velocity, pressure and the path of gases in the cores supporting the user to find the right solution to avoid this defect.

## Possible Root Causes:

- Low permeability of the core sand
- Lack of vents or gas outlets in the molds and cores
- Excessive use of binders, coal or other combustible products in the core and mold making processes
- Low pouring temperature

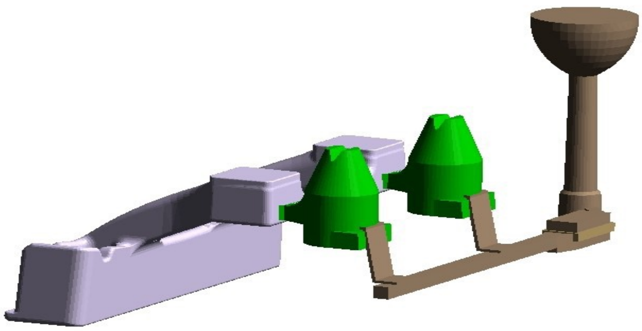
# SAND BURN

## Description:

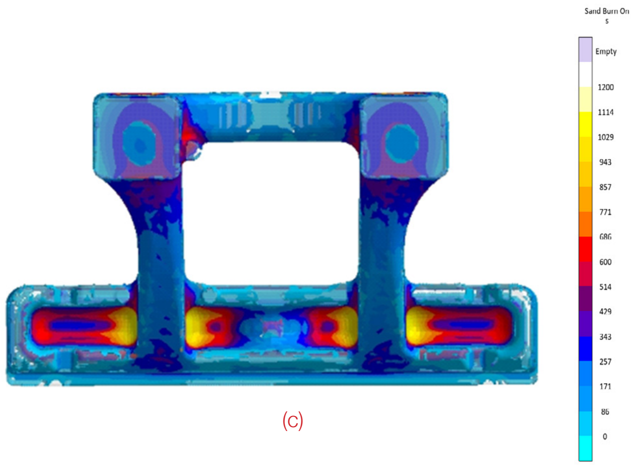
Burn on and penetration shows as a hard skin (Figure 4 a) adhered at the casting surface and are mainly caused by localized overheating of the sand mold or cores. Such over-heating can cause liquid metal to compromise the mold surface and entrain onto the surface of the mold (03).

Burn on is a defect that is possible to be cleaned with more effort than the usual shotblasting, but penetration is a more intensive defect characterised by the penetration of metal against the mould or sand core , creating a superficial crust adhered to the hot spots of the casting, which is hardly eliminated from the surface

(a)



(b)




(c)

▲ Figure 4(a): Hard skin adhered at the casting surface; (b) Original gating layout system; (c) Burn on simulation result showing the critical regions

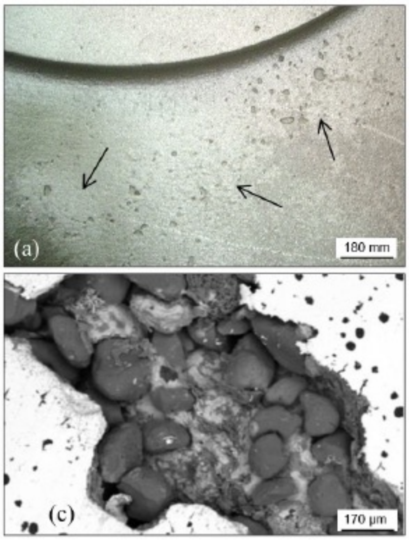
## Simulation Interpretation:

Sand Burn on & Sand Penetration are direct results that show where the critical regions are for the defects. Figure 4c shows the results of sand burn on, indicating the high potential of defect at the bottom areas of the casting.

## Possible Root Causes:

- Excessive pouring temperature
- High metallostatic pressure (casting height is too large)
- Insufficient refractory of mold/core
- Soft mold or uneven compations of the sand
- Location of the Casting/Gating system
- Sand properties such as low sintering point of the base mold material, too coarse sand grain, low conductivity.
- Excessive fines, spent binder, oxides, etc.

# SAND INCLUSION




◀ Figure 5(a): Sand inclusions found in a heavy ducitle iron casting; (b) Micrograph of sand inclusions in ductile iron casting (01)

## Description:

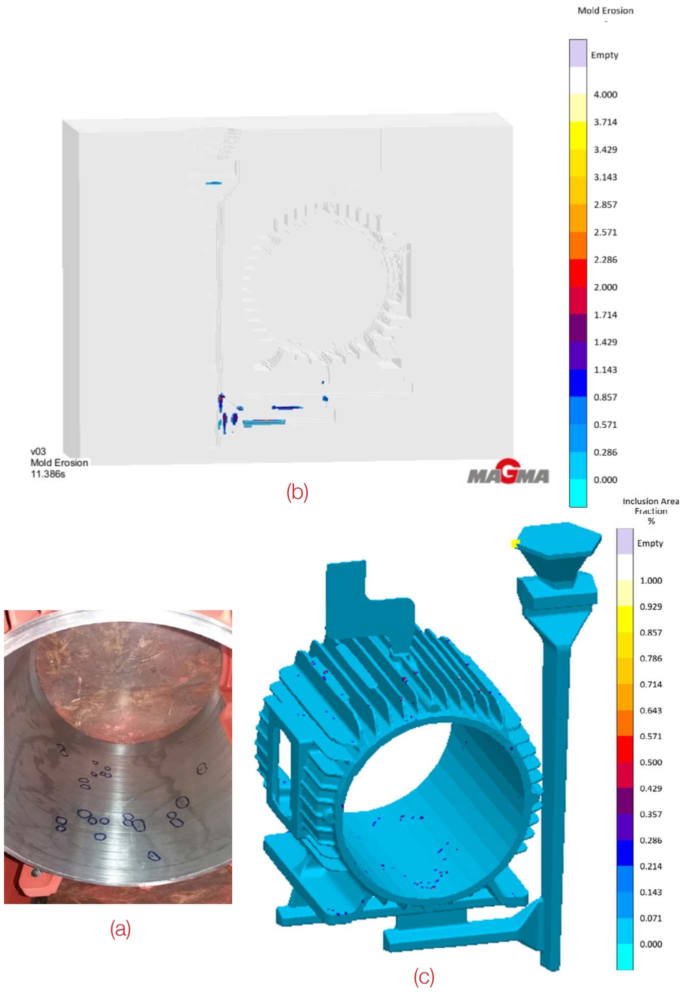
Presence of sand grains on or near the surface of the part (Figure 5 a,c), resulting from erosion of the sand by metal flowing over the mold or cored surface. Sand inclusions can be easily mistaken with slag or reoxidation inclusions when observed with naked eye. Sometimes small sand grains adhering to the internal surfaces makes the identification easier, but the grains can be deteriorated or fractured due to shot blasting and the diagnosis can be only confirmed via metallographic inspection, where the sand grains can be analysed in detail, as shown in Figure 5 b.

## Simulation Interpretation:

Figures 6 a and b show respectively the filling criterion results of mold erosion and sand inclusion area fraction. Mold erosion result indicates where the sand was displaced and inclusion area fraction where the sand inclusions are going to be located in the surface of the casting.

## Possible Root Causes:

- Turbulent and high velocity filling of molds and cores as a result of improper gating system design, promoting mold erosion.
- Poor compaction of sand mixtures during the moulding step (free grains or groups of free grains)
- Low moisture and consequently low compactability of the green sand molds
- High temperature in the mixtures of the sand losing moisture, reducing compactability
- Low bentonite content in the green sand mixtures (bentonite promote strength in the compacted molds)
- The use of sand mixtures with high contents of coarse grains
- Demages produced on any part of molds and cores as a result of bad practice during molding step (01)



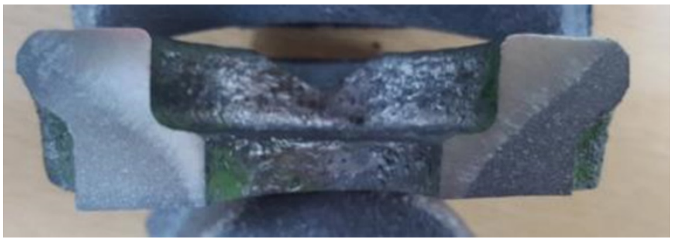

▲ Figure 6 (a): Sand inclusions and oxides in a electric engine housing surface; (b) Mold erosion results in a disamatic green sand mold; (c) Consequent sand inclusion area fraction in the critical location for machining (04).

# CARBIDES

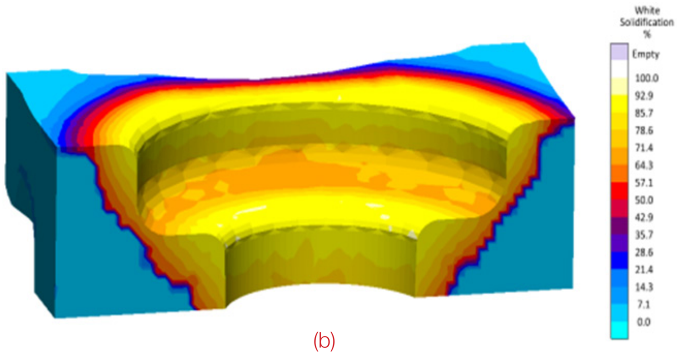
## Description:

Carbides formation in cast iron occurs during the solidification and they are most of the times undesired microstructures that increase the hardness, reduce the toughness and greatly reduce machinability of the castings. Carbides are possible to be detected by hardness measurements or metalography analysis as shown in the figure 7 a. Other techniques are available to evaluate the capacity of a melt to form carbines such as chilling wedges, as shown in figure 7 d and cooling curves from thermal analysis (01).

Usually carbides are formed by difficulties in graphite nucleation and growth for solidification to proceed in the C-Si stable system before the metastable one is reached. It can be caused by fast cooling as shown in the figures 7 a,b and c or by segregation of elements such as Cr, Mo, Vn, that are cabides promoters and facilitate the solidification under the metastable system, in this last case the defect is called inverse chilling.



(a)



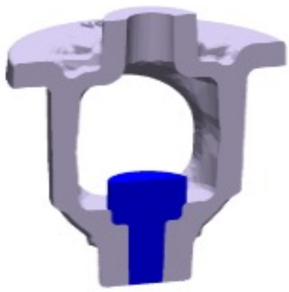

(b)

## Simulation Interpretation:

MAGMAiron is able to simulate the carbides formation in the casting taking into account the inoculation treatment, the cooling rate, and the chemical composition. The result fo white solidification shows directly the location and the percentage of the carbides in the microstructure as exemplified in the Figures 7 b and 8.

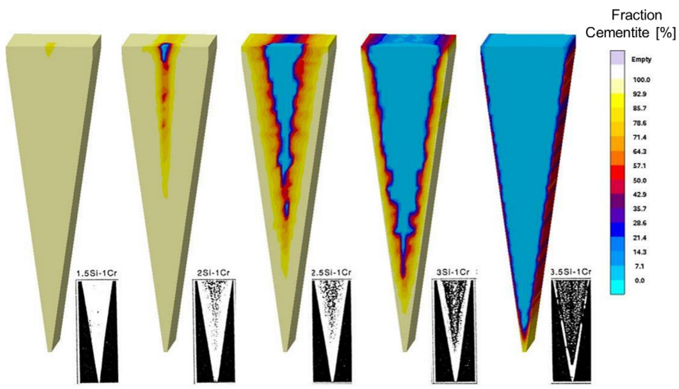
## Possible Root Causes:

- High solidification rates, thin sections or close to chills
- Carbide formers elements such as Cr, Mo, Vn or carbide promoters (limiting graphite growth), such as Mg, Bi and rare earth elements
- Lack of inoculation, or not efficiency inoculation methods
- Fading of inoculant
- Low carbon equivalent hypoeutectic alloys, which Si plays an important role for graphite nucleation
- Long holding times in ladles or melting furnaces reducing the natural nucleation potential of the melt (01)



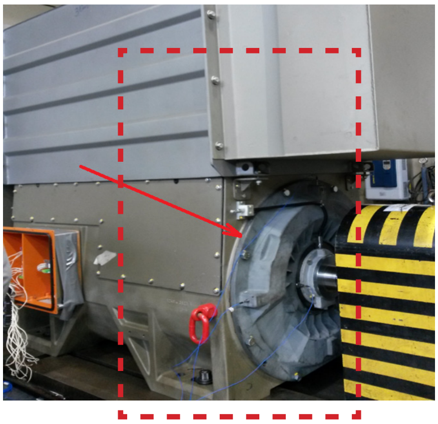
(c)

◀ Figure 7 (a): Part section showing the chilling region in white, caused by fast solidification rate due to chill application; (b) Simulation results of white solidification showing the carbides formation prediction in the same areas; (c) Original design of the part and the chill applied in blue (05)




▲ Figure 8: Edge test simulation and real results, comparing the % of carbides with different Cr content in a cast iron composition

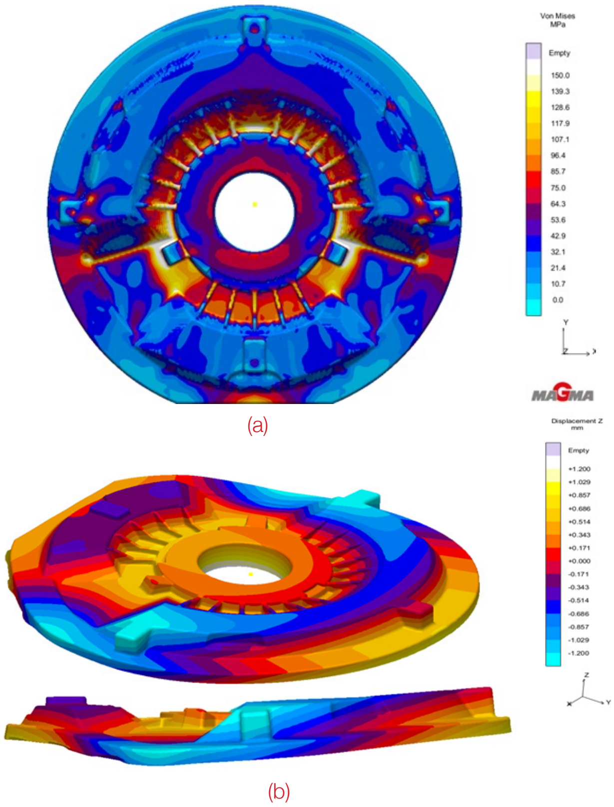
# DISTORTION



▲ Figure 9: Snapshot of the mounted engine cover (06)

## Description:

During solidification and cooling of castings, stresses build up due to thermal gradients introduced by geometry complexity and constraints of core and molds. In some cases, the high stress level leads to permanent deformation that affects the dimensions of the final part. Figure 9 shows a grey iron electric engine cover which the flatness was measured and compared with simulation results. Is possible to observe that the high level of stresses in the inner thin area, around the ribs of the part (Figure 10 a) led to bending tendency, affecting the flatness of the component (Figure 10 b). Flatness deviation was measured in reality and in simulation, as shown in the graph of Figure 11.



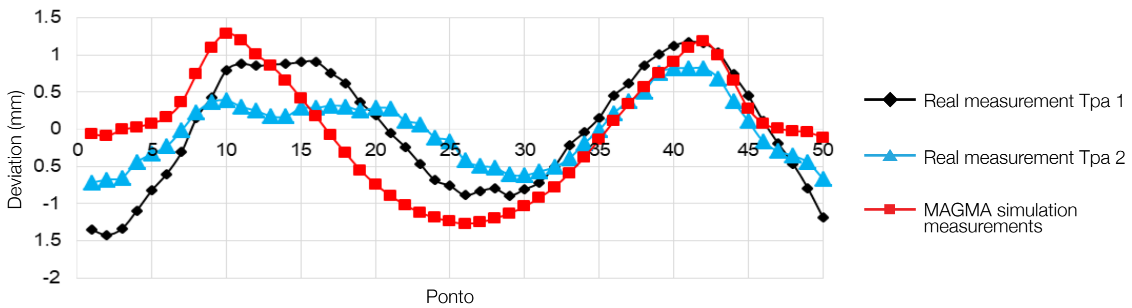

▲ Figure 10: (a) Von Mises stress level after the casting process, showing high stresses around the ribs; (b) Displacement results in Z direction showing the bending tendency (06)

## Simulation Interpretation:

Displacement results in X, Y, Z directions show the movement of the part from its original dimension; it's a combination of thermal shrinkage and shape distortion. With the resource of distortion factor it is easier to visualize the warpage. To evaluate the deviation of the final dimensions it's necessary to compare the distorted part with a reference geometry, or measure for example flatness or roundness using the measurement perspective with different methods such as, best fit, 3 points or 6 points. In Figure 11 the 6 points method was used and compared with real three dimensional machine measurement.

## Possible Root Causes:

- Large differences in section thickness causing high temperature differences and stresses
- Location of feeders and chills causing different solidification times and temperatures
- Design of the casting; long product shapes.
- Early shake out, casting temperatures are to high at the moment of shake out
- Excessive stiffness of the mold and cores causing hindrance and uneven shrinkage




◀ Figure 11: Flatness measurements - blue and black curves show the real measurements of flatness deviation and the red curve shows the deviation in the simulation measurements, using the 6 points method (06)

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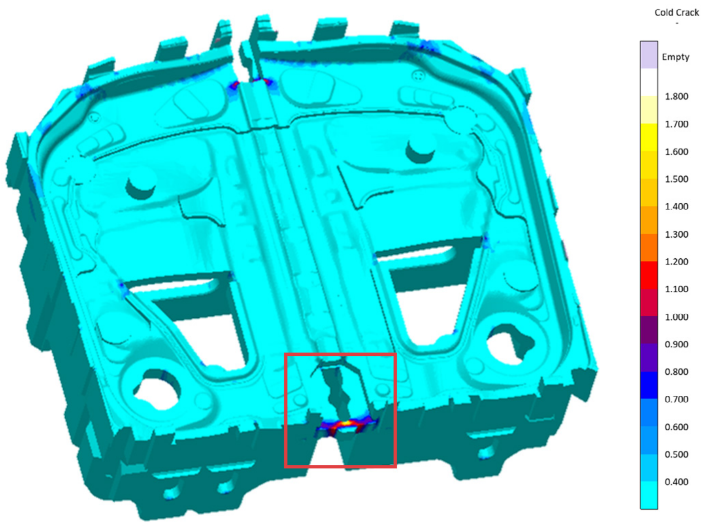
# COLD CRACK

## Description:

Cracks are discontinuities formed at relatively low temperature (below solidus temperature) as shown in the example of Figure 12 (a). The cold cracks occur when the stresses that build up in the part during the cooling phase exceed the ultimate tensile strength of material at a certain temperature. The crack may be transgranular or intergranular, depending on the relative strength of the grains and their boundaries and the temperature at which the crack is formed (07).

(a)




(b)

▲ Figure 12: (a) Cold cracks in the casting; (b) Cold crack criteria simulation result showing the critical regions for the defect

## Simulation Interpretation:

Figure 12 (b) shows the cold crack criteria result. This criteria shows the tendency of cold crack that happened at a certain time/temperature during the cooling phase of the part. Regions higher than 1 means that the von mises stresses exceed the initial tensile strength of the material. Values < 0.8 are not critical, values > 0.8 < 1 need a closer look („gray area“) values > 1 are critical and tend to open a crack in the reality. It's important to notice that the tensile strength of the material under high temperatures is lower than the room temperature.

## Possible Root Causes:

- Damage to casting while hot due to rough handling or excessive temperatures at shakeout
- Stresses in the casting that exceed the tensile strength of the material caused by restriction to movement of the casting by its geometry, mold or cores
- Stresses in the casting caused by an improper heat treatment

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