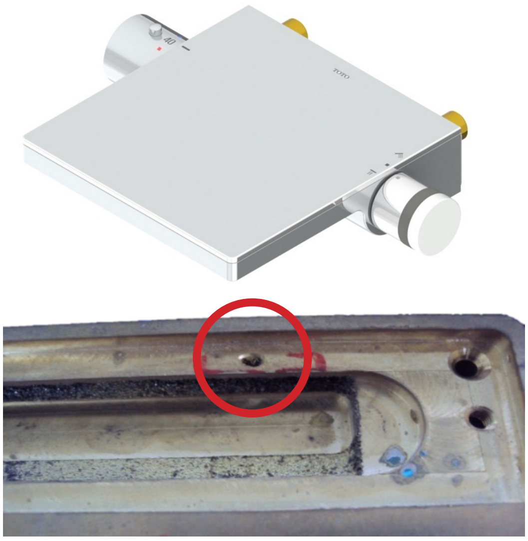
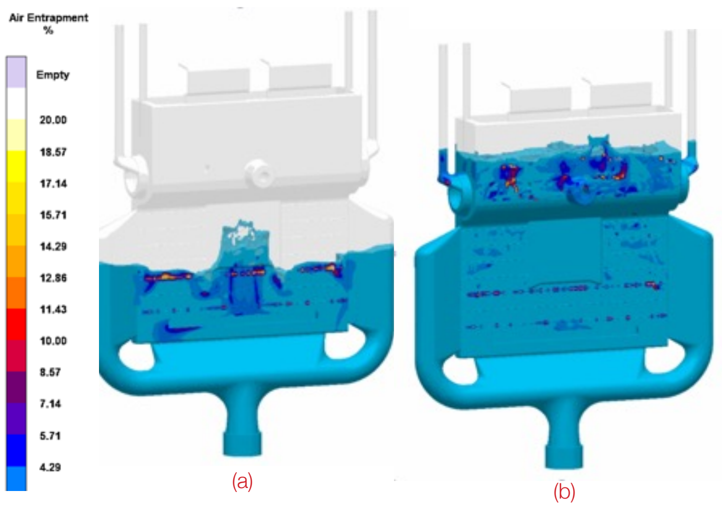
GAS POROSITY



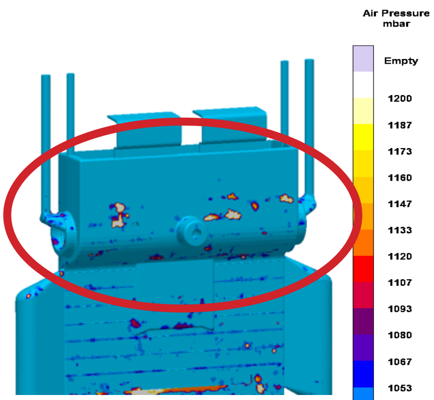
▲ Figure 1: Gas porosity in a brass sanitary product produced by LPDC process[02].

Description:

Gas porosity is one of the most serious problems in the casting of non-ferrous metals. It is generally caused by the evolution of gases during the filling and solidification process[01]. Gas porosity is caused by different sources. The typical root causes are hydrogen absorption during melt preparation mainly for aluminium casting and air entrapment during filling of the cavity. The latter happens most of the time as a consequence of excessive turbulences and/ or inappropriate gating system design (Figure 1). Air porosities appear in the body of the die casting parts, round or oval, with smooth surface. The machined surface can be identified by visual inspection after machining, and the non-machined surface needs to be identified by X-ray detection.



◀ Figure 2: Air entrapment results showing filling sequence (a) Splaches at 40% of the filling; (b) 85% of the filling with high percentage of air entrapped in the melt in the critical region[02].



▲ Figure 3: High air pressure in the critical region indicating bubbles at the end of the filling[02].

Simulation Interpretation:

The results of Air Entrapment shows the evolution of the air that is being entrapped in the melt during filling (Figure 2). Additionally, Air Pressure (Figure 3) shows the regions and at which moment a bubble is being created. To interpret air porosity is usually necessary to evaluate both results.

Possible Root Causes:

Excessive turbulences in the filling:

- High filling velocities, usually higher than 0.5 m/s.
- Inappropriate gating system design, which runs empty and entraps air.
- Inappropriate designing of overflows and vents.

High hydrogen levels in aluminium casting:

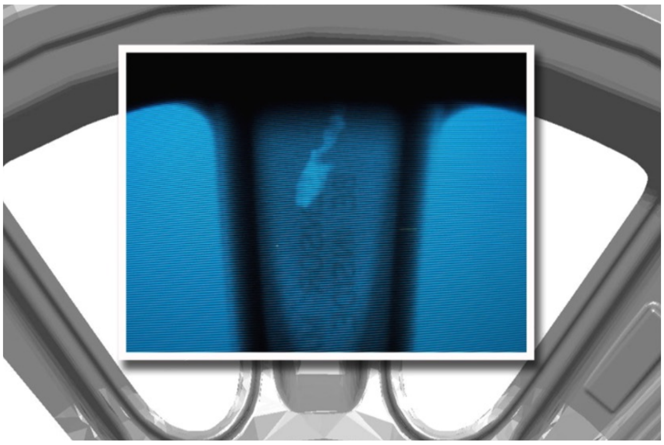
- Sources of hydrogen - Moisture in the air enters the molten metal alloy, moisture or greases on metal alloy ingot, moisture on smelting tools.
- Insufficient or inappropriate degassing process.

[01] 2008 ASM Handbook Castings. Vol. 15, Ohio: ASM International
[02] PT. Surya Toto Indonesia. Casting Quality Improvement with MAGMA simulation. Case study presented in the User Group Meeting ASEAN 2016.

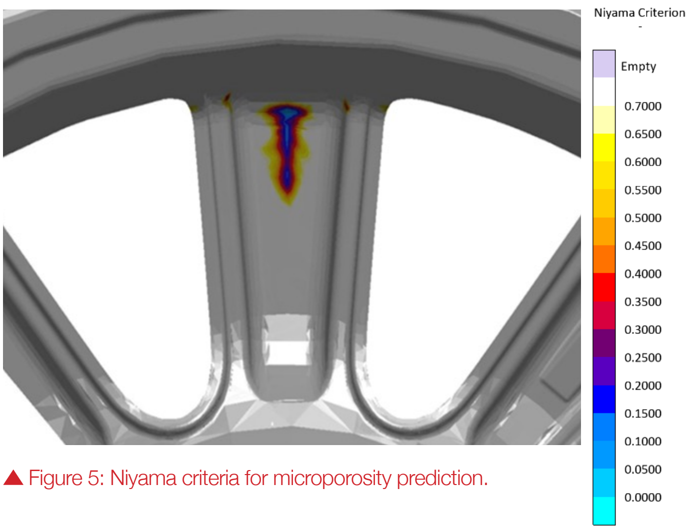
MICROPOROSITY

Description:

Microporosities or centerline porosities (Figure 4) are small voids usually identified with liquid penetrant, ultrasound and X-ray. It occurs where there is a geometry-related feeding requirement. The residual melt coming from the feeder (GDC) or stalk (LPDC) cannot feed these locations sufficiently. These small cavities inside the casting reduces the mechanical properties and usually leads to leakage problems.



▲ Figure 4: Aluminum wheel showing a microporosity in X-Ray analysis.



▲ Figure 5: Niyama criteria for microporosity prediction.

Simulation Interpretation:

Low Niyama result values are a good indicator of poor directional solidification and can help to identify areas that are at risk of having micro-porosity indications. The critical value usually depends on the alloy, but in general, values lower then 0.7 are critical for micro-porosity (Figure 5). The additional 'Microporosity' result is derivated from Niyama and also helps to visualize and compare minor porosity defects quantitatively.

Possible Root Causes:

- Geometry related defect - where there is low thermal gradient and high cooling rates during the solidification, typical example are plates geometries.
- Alloys with high solidification interval.
- Poor directional solidification, dendrite arms isolated from liquid metal from feeding and the subsequent volumetric contraction of the liquid results in micro porosity indications.
- Solutions are usually found by changing the feeding layout, cooling channels position and machining allowance to improve the directional solidification.

OXIDE INCLUSIONS

Description:

Usually the oxides inclusions in aluminum castings are classified as old and young oxides. Old oxides are less flexible inclusions and are formed during the preparation of the melt. Young oxides are thin flexible films (Figure 6), which are formed in the surface of the liquid aluminum alloys and entrapped in the casting during the filling of the die. The oxide defects are highly damaging the mechanical properties to aluminum alloy castings and are one of the most important root causes for leakage (Figure 7).

Simulation Interpretation:

It is necessary to identify the regions with high velocities (> 0.5 m/s) in order to be able to minimize the formation of oxides during the filling of the part. High velocities and metal falls (Figure 8) generates high turbulences and consequently high melt surface exposure to the air during the filling. The oxides particles (Figure 9) help to identify and compare the number of oxides that were created during the filling. Results of air entrapment and air contact are usually useful to identify the regions that were more exposed to the air. The smooth filling results in the optimization perspective support the comparison of the free surface area between different designs in the virtual DOEs, showing the filling profile that presents less air exposure.

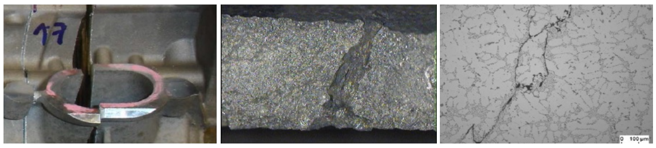
Possible Root Causes:

Old oxides:

- Unfiltered virgin ingot.
- "Dirty" remelt (gating, scrap castings, machining chips): moisture, oils/cutting fluids, screens/filters, mold/core sand.
- Oxide/Corundum buildup on furnace walls.
- Lack of adequate filtration and degassing/fluxing.
- Stirring in furnace.
- Moisture on treatment tools.

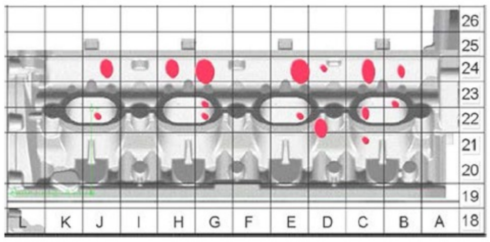
Young oxides:

- Metal Transfer
  - Entrapped oxide skins in the surface, ladle, launder system.
  - Excessive melt drop from ladle/launder to mold: high velocity and turbulence.
  - Refilling of low pressure furnace, melt drop and creates agitation of oxide skin.
- Gating system
  - High melt velocity (above 0.5 m/s).
  - Broken metal fronts due to turbulence.
  - Creation of air pockets inside the gating system.
  - Metal falls to the drag box.
  - Entrapped air due to collapsed pockets.

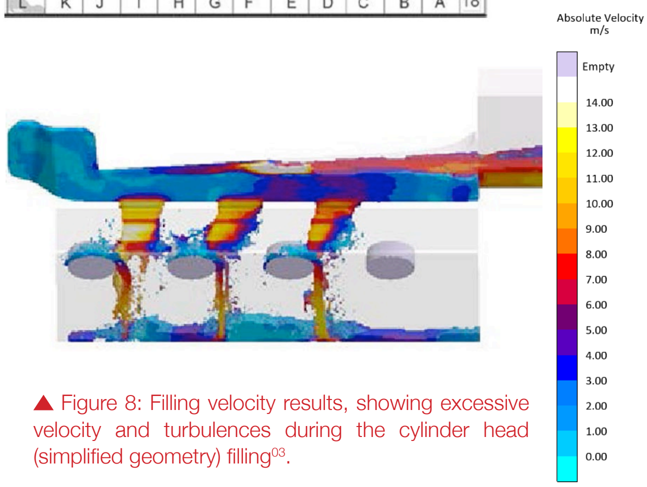


(a) (b) (c)

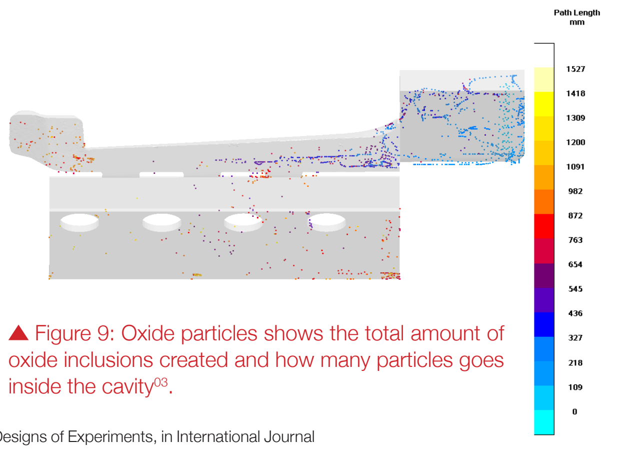
▲ Figure 6: Root cause analysis on a leaking cylinder head: (a) Leak tests under water indicate two leakers through rising bubbles; (b) The fracture analysis shows an oxide skin spanning the entire thin wall; (c) The microstructure analysis confirms the cause for the leaker[03].



◀ Figure 7: Leakers evaluation - due to oxide inclusions in the cylinder head casting[03].



▲ Figure 8: Filling velocity results, showing excessive velocity and turbulences during the cylinder head (simplified geometry) filling[03].



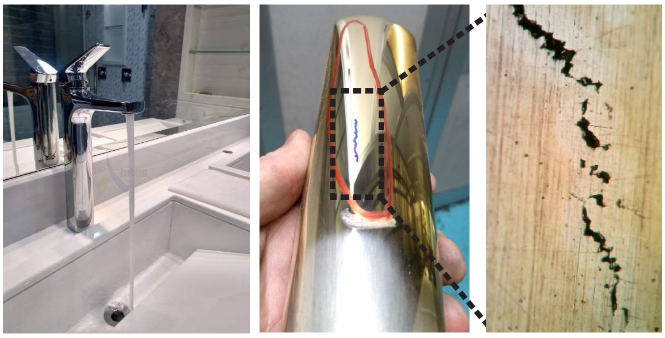
▲ Figure 9: Oxide particles shows the total amount of oxide inclusions created and how many particles goes inside the cavity[03].

[03] Sturm J.C., Pavlak L. Reduction of Oxide Inclusions in Aluminum Cylinder Heads Through Autonomous Designs of Experiments, in International Journal of Metalcasting, vol.11, nr.2. American Foundry Society, 2017.

HOT TEAR

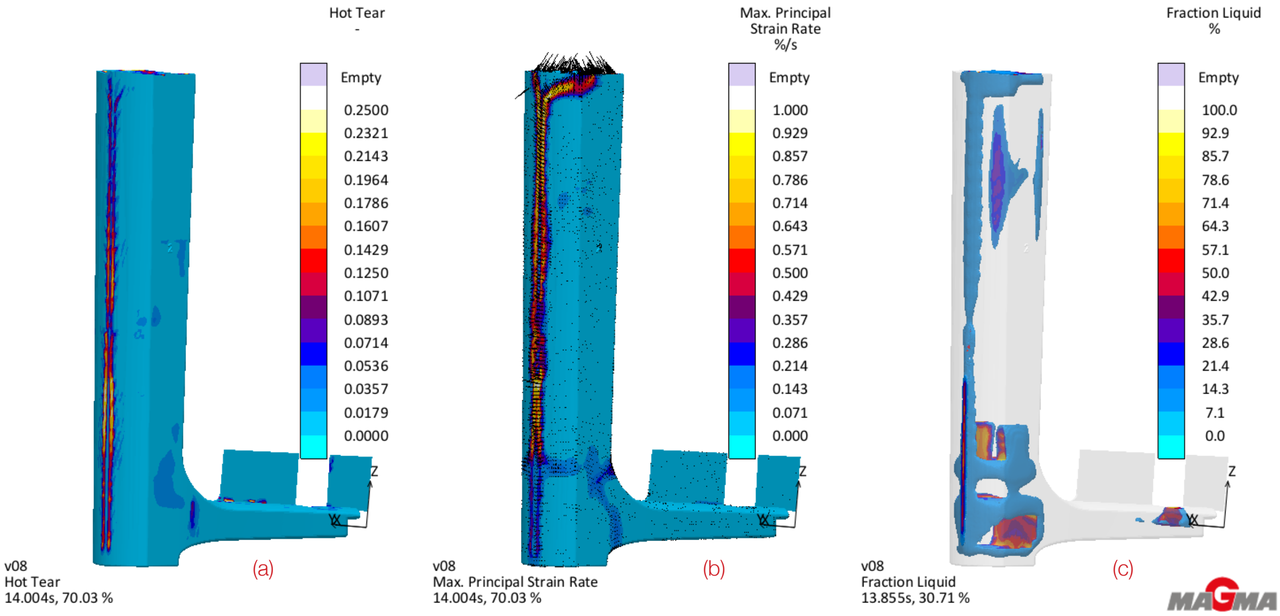
Description:

Hot tears are typically a zig-zag fracture pattern - interdendritic/intergranular fracture (Figure 10b & 10c). The tears initiate and propagate along grain boundaries. Hot tearing occurs at a late stage of solidification. When the casting cools down, it contracts and thermal stresses developed. The thermal stresses are not the only factor to cause the development of hot tears, because the material is not completely solidified. The causes are the stresses in solidified areas surrounding the critical zone and also the constraints from mold and cores. The stresses in the solidified areas "pull" the critical area under solidification, generating strains and hot tears risk.



(a) (b) (c)

Figure 10(a): Brass faucet application; (b) Casting after polishing process - showing hot tear on surface; (c) Amplification of the the crack showing the zig-zag morphology[04].



▲ Figure 11(a) Hot tear criterion; (b) Maximum principal strain rate result; (c) Fraction liquid results[04]

Simulation Interpretation:

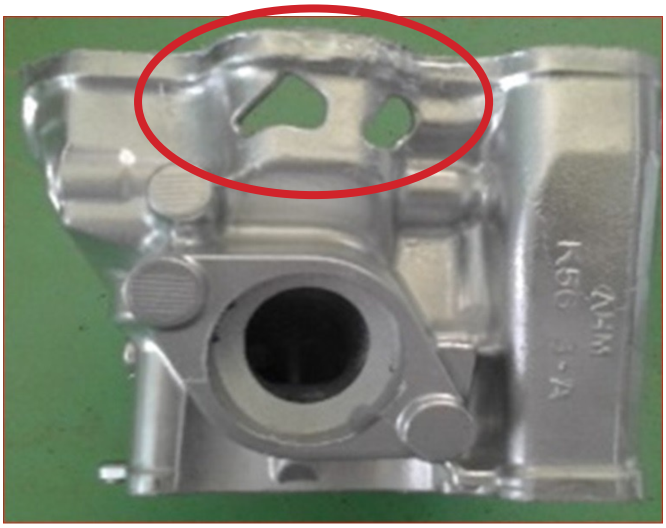
The hot tearing tendency in casting can easily be evaluated by using the hot tear criterion. MAGMASOFT® calculates the hot tear criterion by evaluating the strain rate during the solidification from the moment when no further feeding through the dendrite network is possible. The hot tear result criterion (Figure 11a) indicating the risk of hot tear at the area close to the radius in the gating area. Together with the hot tear criteria, it is necessary to analyse the evolution of the maximum mechanical strain rates during the late stages of solidification (Figure 11b), the stresses in the surroundings areas and the fraction of liquid in the critical regions (Figure 11c).

Possible Root Causes:

- Large freezing range alloys promotes hot tearing due to a longer time spent by the alloy in a vulnerable state (examples: low % Si in AlSi alloys).
- Hindered contraction due to design.
- Large differences in section thickness.
- Sharp radius in casting design.
- Abrupt transitions in thickness, branching & connected sections.
- Excessively core stiffness causing high resistance.

[04] Docol case study courtesy - Conserving Resources and Protecting the Environment With MAGMASOFT - MAGMAtimes vol. 36 nr. 3 pag 6. Publication of MAGMA Geissreitechnologie GmbH. Aachen 2021

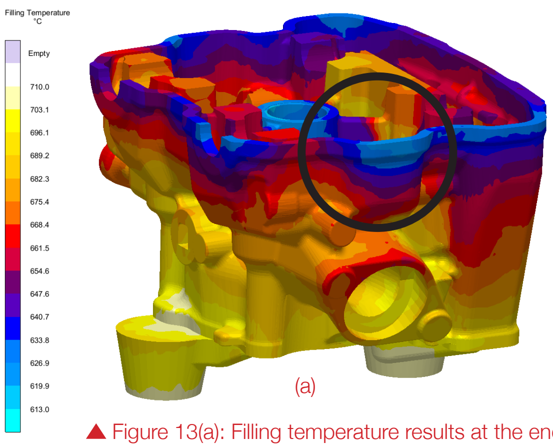
MISRUN/COLD LAP/ COLD SHUT



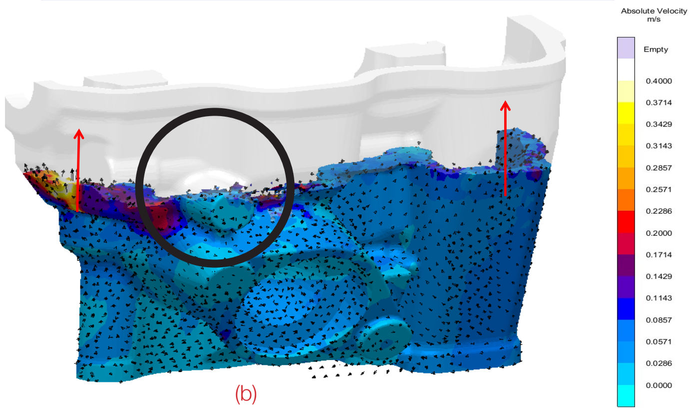
▲ Figure 12: Misrun in a motorcycle cylinder head produced by LPDC.

Description:

Cold shut, cold laps and misruns are the typical surface defects that have similar root causes, but changes 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[05]. This defect is visible in 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. Misruns (Figure 12) occured 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 13(a): Filling temperature results at the end of filling - showing temperatures close to the liquidus temperature of the alloy.



▲ Figure 13(b): Low velocities in the critical region.

Simulation Interpretation:

A detailed analysis of the cavity filling temperature (Figure 13a) and velocity behaviour (Figure 13b) allows to visualize the flow behaviour. 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.

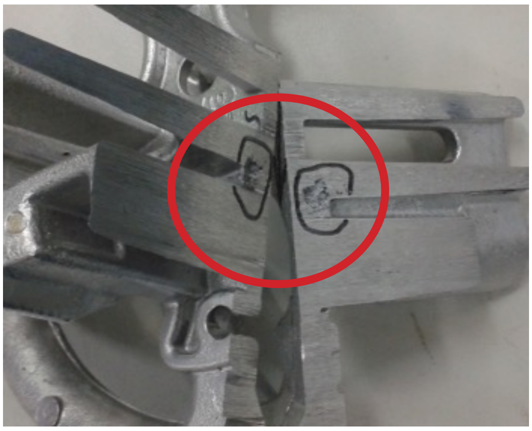
Possible Root Causes:

- Low pouring temperature.
- Interrupted pouring time.
- Low die temperature.
- Air entrapped in the flow front - low number or wrong overflows position.
- Long flow distance with low velocity.
- Non-optimized gate position - to minimize narrow cross-path and ensure short flow path.
- Low height difference between the top level of pouring cup and top area of the cavities.
- Filling failure due to internal gas, which cannot be evacuated quickly to open air - lack of ventilation.

[05] Sunny, W. 21 Casting Defects and How to Prevent Them in Your Products. Manufacturing and QC blog. 18 Sep. 2018 (https://www.intouch-quality.com/blog/21-casting-defects-and-how-to-prevent-them-in-your-products)

SHRINKAGE POROSITY

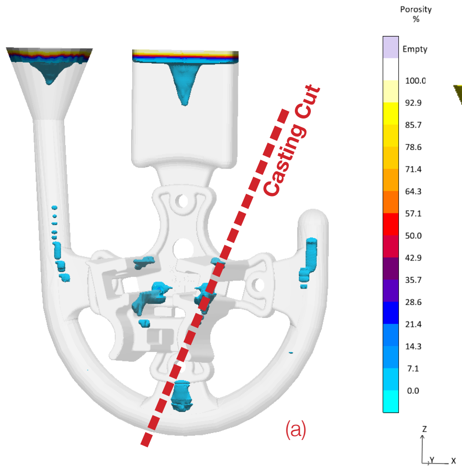
▲ Figure 14(a): “Clamp base” produced by permanent mold gravity die casting



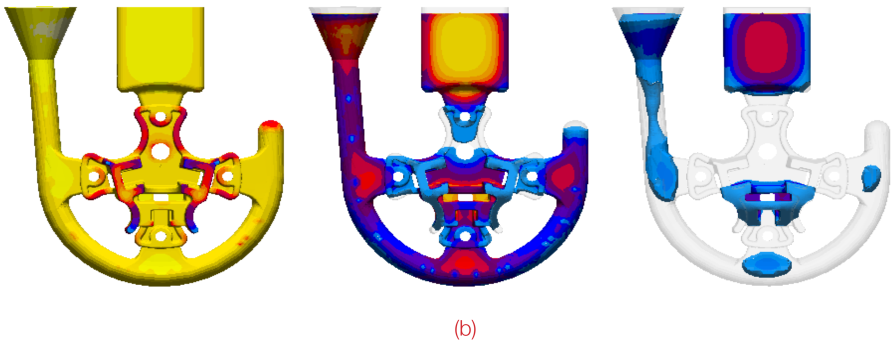
▲ Figure 14(b): Shrinkage porosity defect in the hotspot area[06]

Description:

Shrinkage porosities or macro porosities are discontinuities resulting from volume contraction during the transformation from liquid to solid phase and occured when liquid metal is no longer available to feed the volumetric contraction of the solidifying metal Figure 15b. The defect is intimately connected with alloy composition, feeding paths, feeder and runner layouts.



▲ Figure 15(a): Porosity results showing the regions with shrinkage porosity defects[06].



▲ Figure 15(b): Fraction liquid sequence results showing regions of liquid isolation at the end of the solidification.

Simulation Interpretation:

The fraction liquid (Figure 15b) and temperature results, show the solidification path and when the hot spot is isolated. FStime shows the time (dentrite coeherency time) that feeding is not possible anymore. Hot spots and porosity (Figure 15a) shows the location, volume and intensity of the shrinkage porosity.

Possible Root Causes:

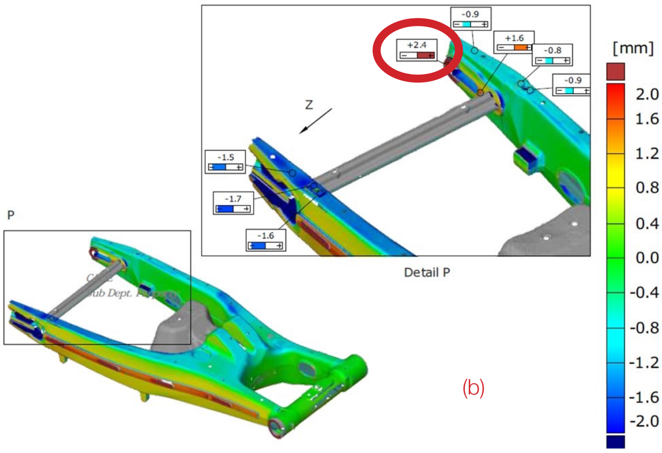
- Casting designs creating isolated hotspots that are not addressed via the gating and feeding system.
- Inadequate feeding path with in casting or riser/ gating to provide feed metal.
- Lack of directional solidification leading to improper temperature gradient being established.
- Alloy composition.
- High pouring temperature.
- Inappropriate cooling system or not suitable start/ stop time.
- High pouring temperature.
- Excessive local temperatures in the die.
- Not suitable die coating process.

[06] PLP Indonesia case study courtesy - Conserving Natural Resources Exploiting Economic Opportunities - MAGMAtimes vol. 37 nr. 1 pag 1. Publication of MAGMA Geissreitechnologie GmbH. Aachen 2022.

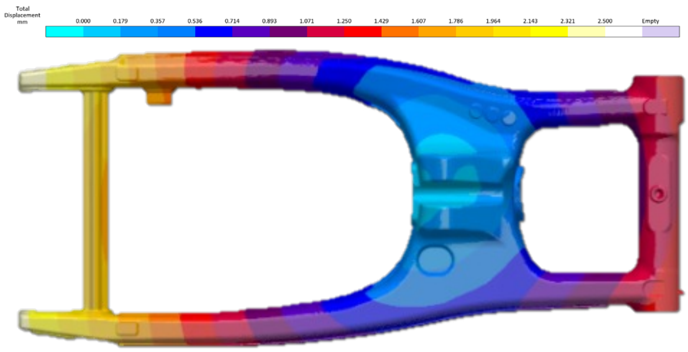
DISTORTION

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 16b shows the dimensional deviation analysis between the CAD geometry and the final scanned casting.



▲ Figure 16(a): Swingarm produced by gravity rotacast process; (b)Dimension deviation between CAD file and scanned real casting, showing maximum deviation of 2.4 mm in the circled region.



▲ Figure 17: Total distortion results - showing the displacement of the geometry. Similar values ≅2.5 mm in the critcal region.

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 (Figure 17). 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 and roundness using the measurement perspective with different methods, i.e., best fit, 3 points or 6 points.

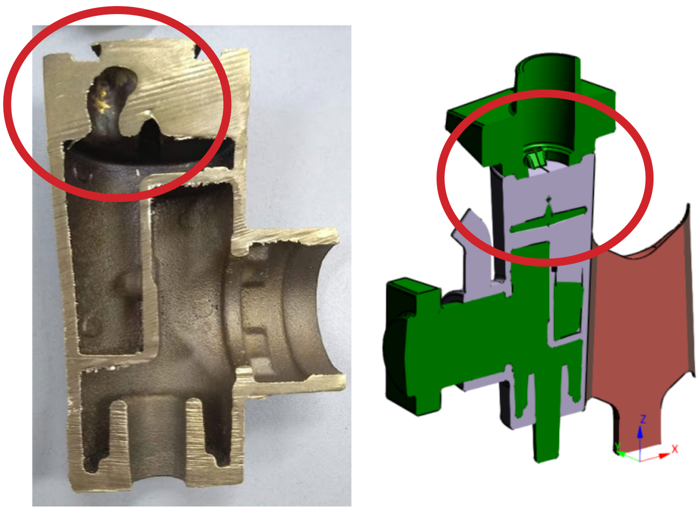
Possible Root Causes:

- Large differences in section thickness causing high temperature differences and stresses.
- Location of cooling lines in the die.
- Design of the casting; long product shape.
- Early shake out; casting temperatures are too high in the moment of shake out.

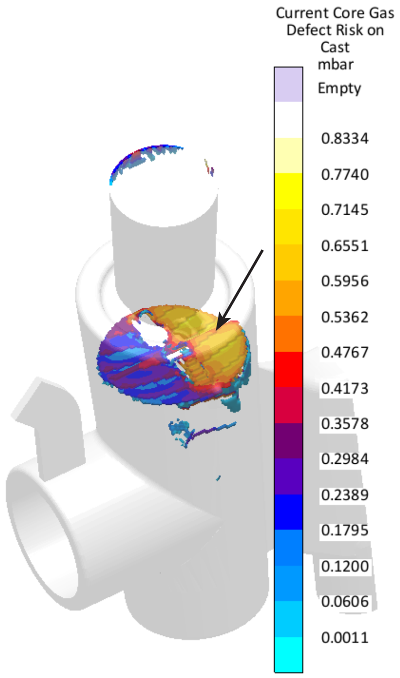
CORE GAS

Description:

Core gas porosity is also called blow holes, 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 (Figure 18b and 18c).



▲ Figure 18(a): Faucet brass component; (b) Blow hole in the upper region of the core; (c) Cut showing the internal geometry of the core. (Case study Docol Metais Sanitarios courtesy)



▲ Figure 19: Current Core Gas Defect Risk on Cast result showing the location of the core gas porosities (Case study Docol Metais Sanitarios courtesy)

Simulation Interpretation:

The result of Current Core Gas Defect Risk on Cast (Figure 19) 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 are different results available to analyse 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 or other combustible products in the core and mold making process.

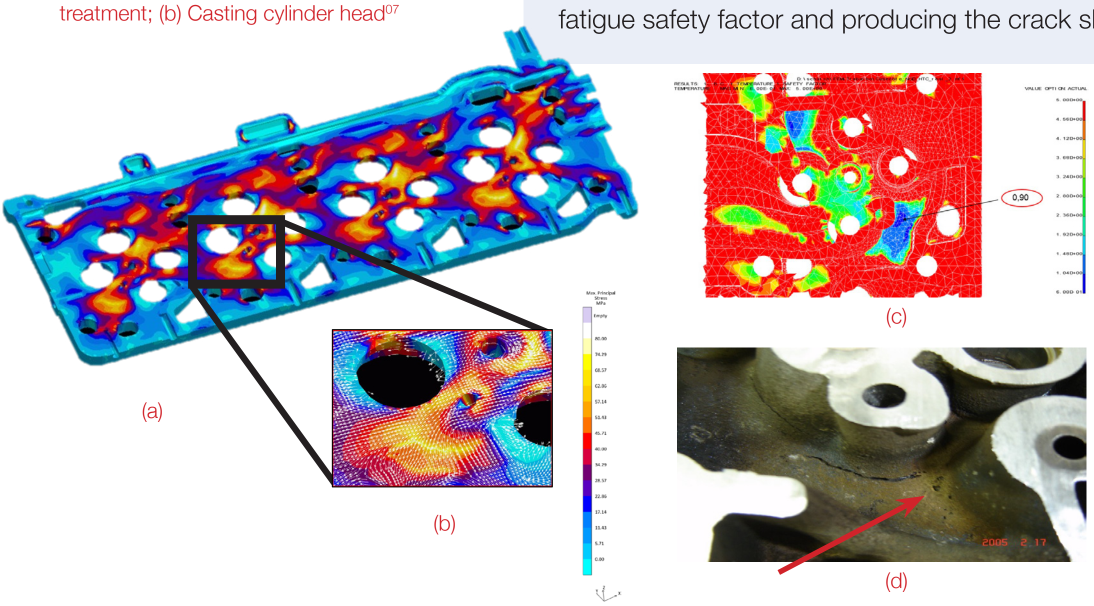
CRACKS

(a) (b)

▲ Figure 20(a): Cylinder head basket for heat treatment; (b) Casting cylinder head[07]

Description:

Cracks are discontinuities formed at relatively low temperature (below solidus temperature), during the cooling in the casting process or quenching in the heat treatment process. The 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 residual stresses developed in casting and heat treatment process can be in the same direction of operational stresses reducing the fatigue safety factor causing cracks during the part application. A cylinder head of a pickup vehicle that cracked due to the high residual stresses built up during heat treatment (Figure 21a & 21b). The residual stresses were mapped in the structural analysis of the part as shown in Figure 21c, reducing the fatigue safety factor and producing the crack shown in the Figure 21d.



▲ Figure 21(a): Cut showing the cylinder head tensile residual stresses result - maximum principal stress; (b) Cut detail showing vectors indicating the direction of the stresses; (c) FEM analysis showing safety factor lower than 1, after considering the heat treatment residual stresses in the structural calculation; (d) Cracks due to high residual stresses after heat treatment that are in the same direction as the operational stresses creating a crack during the part application[07]

Simulation Interpretation:

During the casting cooling or heat treatment quenching is possible to analyse cracks by the cold crack criteria result, which shows easily the tendency of a crack in a certain time/temperature . 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. But the cracks can also happen during the application of the part due to high values of residual stresses (Figure 21a and 21b) that built in the casting or heat treatment process. This residual stresses can be added to the part application stresses and be the root cause for the crack (Figure 21c and 21d).

Possible Root Causes:

- Stresses in the casting process that exceed the tensile strength of the material caused by restriction to movement of the casting by its geometry, mold or cores
- Stresses during quenching in heat treatment process exceed the tensile strength of the material causing cracks
- Residual stresses from casting or heat treatment process are mapped to the structure analysis causing cracks during the casting application.

[07] Silva, W.C.; Pecula M.M.; Stuewe L. -Avaliação da influência do processo de manufatura na durabilidade de um cabeçote de cilindros em alumínio para motores diesel. 13° Simpósio de Testes e Simulações - SAE Brasil, São Paulo 2015.

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4. Docol case study courtesy - Conserving Resources and Protecting the Environment With MAGMASOFT - MAGMAtimes vol. 36 nr. 3 pag 6. Publication of MAGMA Geissreitechnologie GmbH. Aachen 2021.
5. Sunny, W. 21 Casting Defects and How to Prevent Them in Your Products. Manufacturing and QC blog. 18 Sep. 2018. Link: https://www.intouch-quality.com/blog/21-casting-defects-and-how-to-prevent-them-in-your-products
6. PLP Indonesia case study courtesy - Conserving Natural Resources Exploiting Economic Opportunities - MAGMAtimes vol. 37 nr. 1 pag 1. Publication of MAGMA Geissreitechnologie GmbH. Aachen 2022.
7. Silva, W.C.; Pecula M.M.; Stuewe L. -Avaliação da influência do processo de manufatura na durabilidade de um cabeçote de cilindros em alumínio para motores diesel. 13° Simpósio de Testes e Simulações - SAE Brasil, São Paulo 2015.

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