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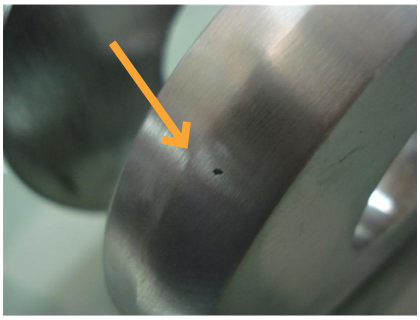
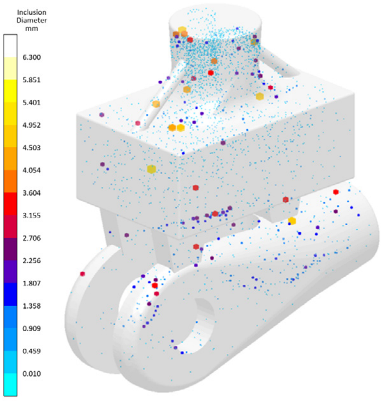
REOXIDATION INCLUSION

Description:

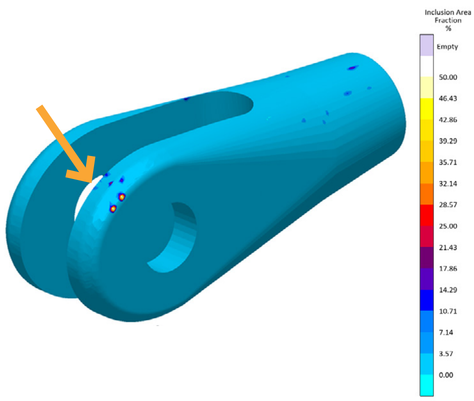
Inclusions are most of the time non-metallic phases embedded in a metallic matrix. They are simple oxides, sulphides, nitrides, or their complexes in ferrous alloys. The inclusions can be exogenous or indigenous. Exogenous are inclusions that are caused by external sources such as slags, refractory material, mold material inclusions. Indigenous or reoxidation inclusions are inherent in the molten metal treatment as a result of unwanted reaction between the melt surface with the air. Melt reoxidation with air can take place at a number of locations in the pouring process where the melt surface is exposed to the atmosphere during the filling. The inclusions act as stress raisers and reduce the mechanical properties of the part (1).



▲ Figure 1: Inclusions in the final casting



▲ Figure 2: Inclusions diameter tracer result



▲ Figure 3: Inclusions area fraction (%), showing in the casting surface the defect of reoxidation inclusion

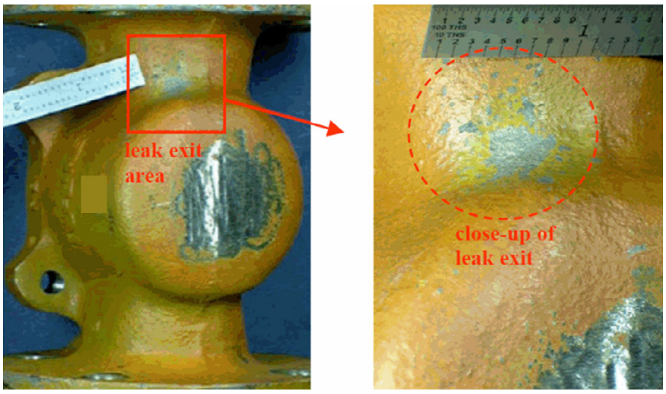
Simulation Interpretation:

In MAGMASOFT® the entire life cycle of reoxidation inclusions is simulated in an independent reoxidation model. The inclusion diameter tracer in Figure 2 shows the formation, growth, movement and agglomeration for the inclusions. At the end of the filling it is possible to analyse the distribution of the inclusions in the casting and the greater diameters show the highest tendency for the defect in the practice. In order to quantify the surface quality, the so-called Inclusion area fraction is calculated from the reoxidation inclusions on the surface (Figure 3). To be able to minimize the formation of reoxidation, inclusion is necessary to evaluate the filling velocities and identify regions with high velocities, high turbulence and high exposure to the air during the mold filling.

Possible Root Causes:

- Large melt contact surface with the air due to turbulence during filling/pouring
- High velocities in the sprue and runners or in the cavity that increases turbulence and exposure to the air
- Melt flow falls from runners and gates into the cavity
- Excessive velocities after the filters
- Runners and gate that runs empty during the filling
- Vortex and high turbulences mixing the melt with air during the filling due to not suitable dimensions and the position of gating system

MICROPOROSITY

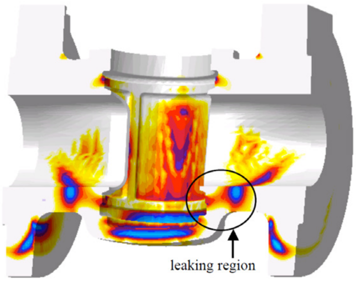


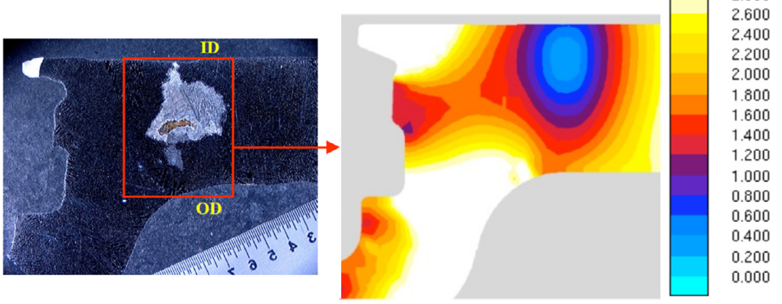
▲ Figure 4: Pump casting investigated to find the root cause of a leak that occurred while in service (02)

Description:

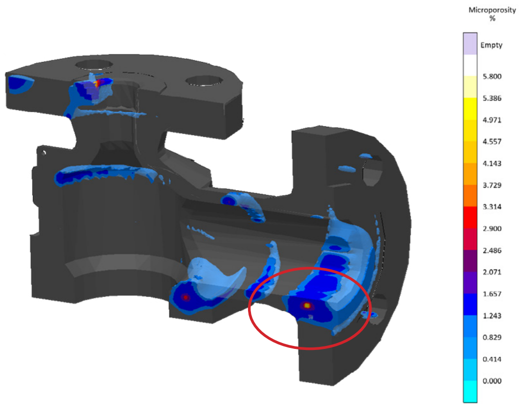
Microporosities or centerline porosities are small voids usually identified with liquid penetrant, ultrasound and X-ray. It occurs where there is a geometry-related feeding requirement. The residual melt coming from the feeder cannot feed these locations sufficiently. These small cavities inside the casting reduces the mechanical properties and usually leads to leakage problems as shown in the figures 4 and 5.

Figure 5: (a) photograph of the cross-section of the leaking region; (b) simulation with Niyama criteria creterion view of the valve wall containing the microporosity that causes the leakage (02) ▼





(a) (b)



▲ Figure 6: Microporosity results showing the critical region for microshrinkage

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 1 are critical for micro-porosity (Figure 5b). Figure 6 shows the 'Microporosity' result in MAGMASOFT® and it 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 microporosity indications. Solutions are usually found changing the feeding layout, chills position and machining allowance to improve the directional solidification.

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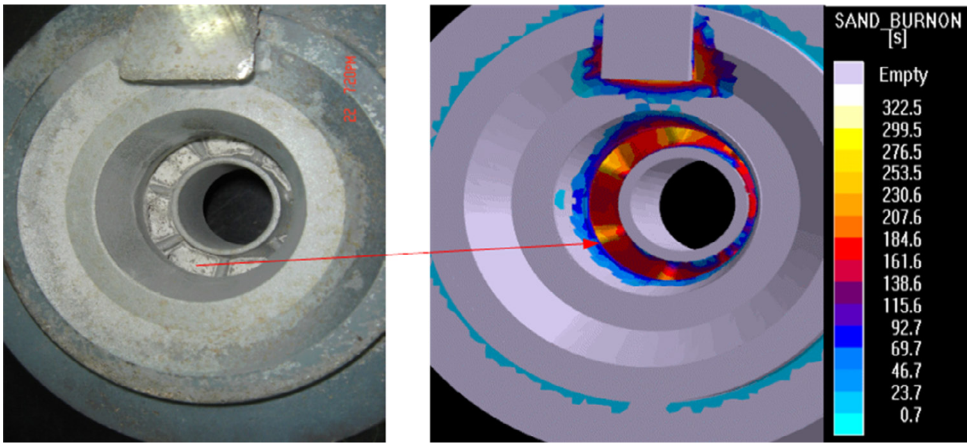
SAND BURN ON AND SAND ENETRATION

Description:

Burn on and penetration shows as a hard skin (Figure 7a) 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 shot blasting, but penetration is a more intensive defect characterised by the penetration of metal against the mould or sand core (Figure 8), creating a superficial crust adhered to the hot spots of the casting, which is hardly eliminated from the surface.



(a) (b)

▲ Figure 7: (a) Noticeable burn on defects in center section of casting; (b) Sand burn on simulation results showing the critical regions in the inner center of the casting

▲ Figure 8: Comparison of predicted and observed penetration defects (03)

Simulation Interpretation:

Sand Burn on & Sand Penetration are direct results that show where the critical regions are for the defects. Figure 7 shows the results of sand burn on, indicating the high potential of defect at the inner center of the casting and Figure 8 shows the comparison of sand penetration between reality and simulation.

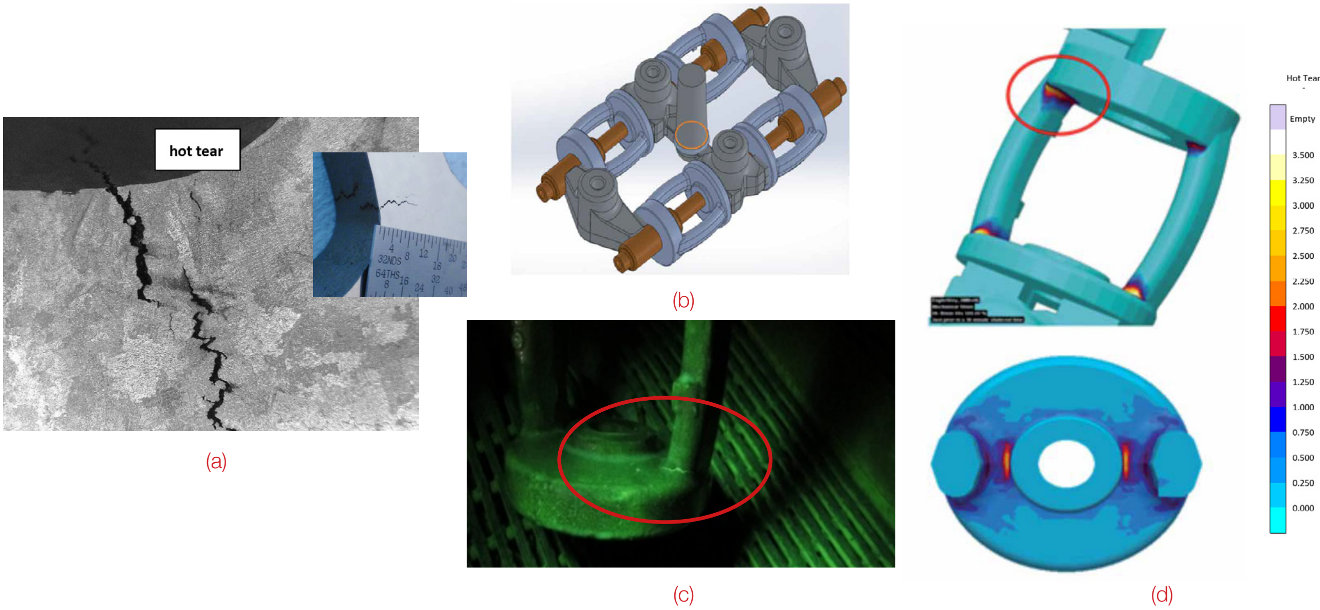
Possible Root Causes:

- 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.

HOT TEAR

Description:

Hot tears are typically a zig-zag fracture pattern (interdendritic / intergranular fracture), as shown in figure 9 (a). The tears initiate and propagate along grain boundaries and are usually heavy oxidazided. Hot tearing occurs at a late stage of solidification where the fraction solid is close to one. When the casting cools down it contracts and thermal stresses develop. The thermal stresses alone are not a cause for the development of hot tears, because the material is not completely solidified, the cause are the stresses in solidified areas around 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 the hot tears risk.



▲ Figure 9: (a) Typical zig-zag fracture pattern of a hot tear; (b) Original situation of the CAD model of the casting; (c) The problem of hot tear defect identified by magnetic particle inspection; (d) Hot tear criterion in simulation showing the critical regions

Simulation Interpretation:

Hot Tear result criterion (Figure 9d) indicates the risk of hot tear problem at the area near the radius. Together with the hot tear criteria is necessary to analyse the fraction of liquid in the critical regions, the mechanical strain rates in critical regions and stresses of the surrounding areas.

Possible Root Causes:

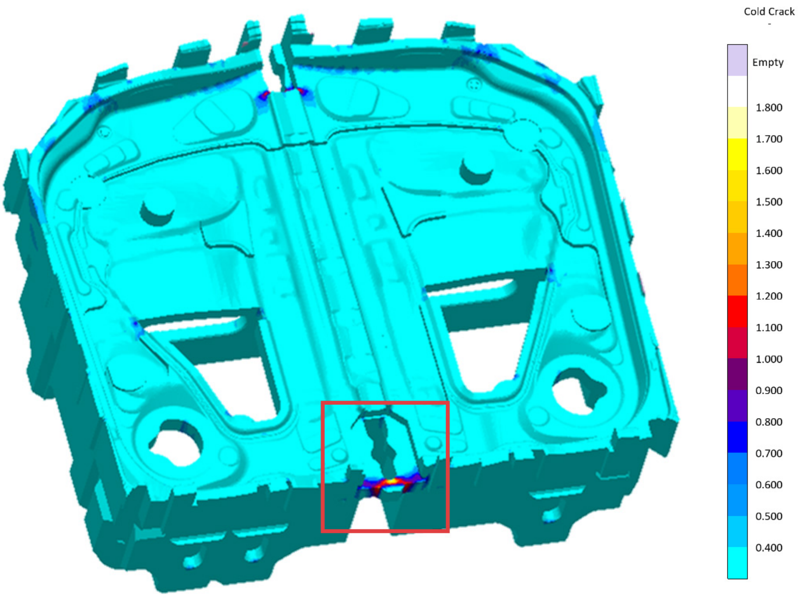
- Hindered contraction due to design
- Large differences in section thickness
- Sharp radius in casting design
- Abrupt transitions in thickness
- Too many branching, connected sections
- Excessively mold or cores stiffness causing high hindrance
- Large solidification interval such as low carbon steels

COLD CRACK

Description:

Cracks are discontinuities formed at relatively low temperature (below solidus temperature) as shown in the example of Figure 10a. 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 (04).

(a)



(b)

▲ Figure 10: (a) Cold cracks in the casting; (b) Cold crack criteria simulation result showing the critical regions for the defect

Simulation Interpretation:

Figure 10 (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.

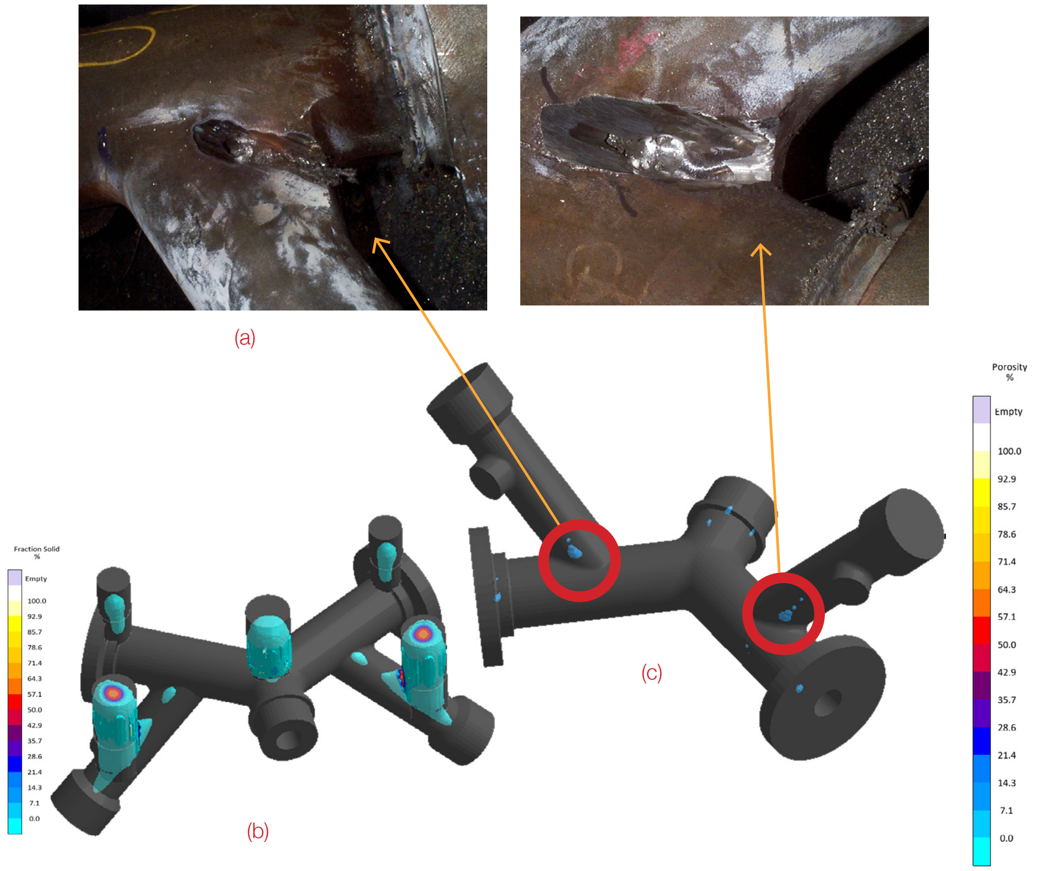
Possible Root Causes:

- 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

SHRINKAGE POROSITY

Description:

Shrinkage porosities or macro porosities are discontinuities resulting from volume contraction during the transformation from liquid to solid phase and occur when liquid metal is no longer available to feed the volumetric contraction of the solidifying metal, as shown in Figure 11a. The defect is intimately connected with alloy composition, feeding paths, feeder and runner layouts.



▲ Figure 11: (a) Shrinkage porosity in the practice; (b) Fraction liquid result at the end of solidification, showing regions of liquid isolation; (c) Shrinkage porosity result showing the regions with higher tendency of defect and correlation with the reality

Simulation Interpretation:

Fraction Liquid (Figure 11b) and Temperature results, show the solidification path and when the hot spot is isolated. FS Time shows the time that feeding is not possible anymore. Hot spots and Porosity (Figure 11c) shows the location, volume and intensity of the shrinkage porosity.

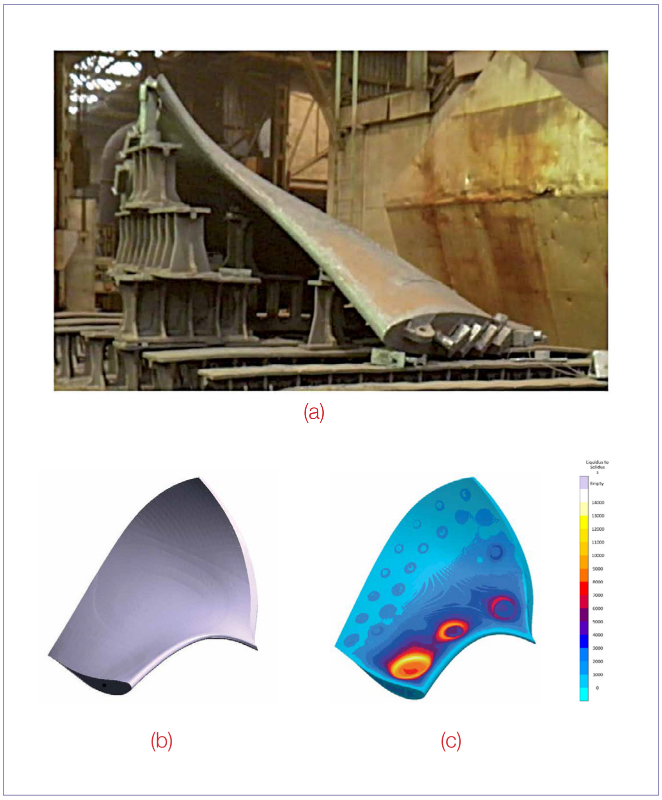
Possible Root Causes:

- Isolated hot spot areas in the casting
- Too high pouring temperature
- Lack directional solidification to the feeders
- No feeding paths in the component
- Small thermal modulus of the feeder neck
- Nof sufficient volume of feeder or not suitable exothermic sleeves, resulting in porosities underneath the feeders
- Long feeding distance between the feeders
- Macrosegregation changing the feeding conditions in the last areas to be solidified

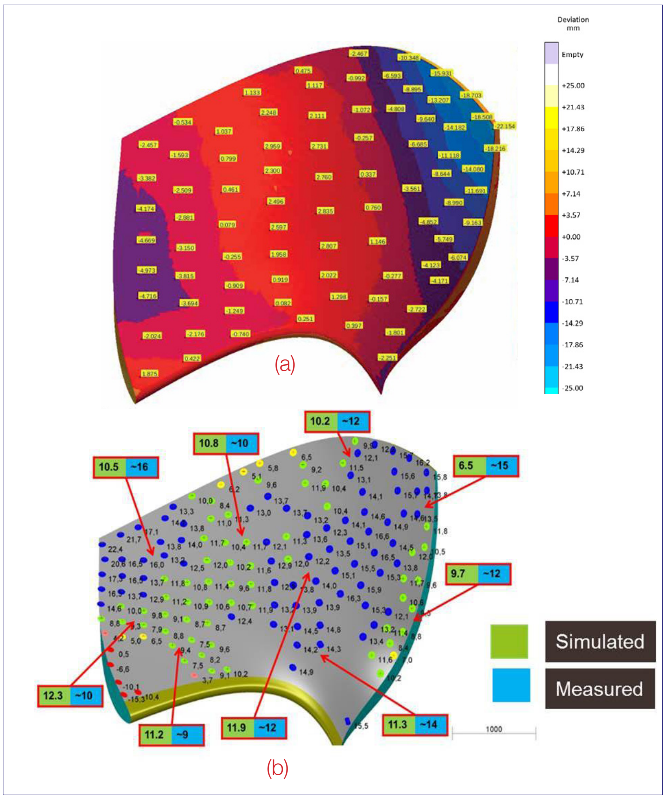
DISTORTION

Description:

As already explained in the description of other defects, 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. The Figure 12c shows the high temperature gradient in the solidification of a francis turbine blade and Figure 13 a,b shows deviation from the reference geometry due to stresses and permanent deformation.



▲ Figure 12: (a) Casting blade of a francis turbine; (b) The geometry of the blade; (c) The liquidus to solidus result from the casting simulation (b) (06)



▲ Figure 13: (a) Deviation between the simulated distortion and the target geometry: Initial calculation (b) Deviation between production part and the target geometry. Numbers in green boxes are simulation results and numbers in blue boxes are real measurements (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 as shown in the Figure 13 (a), or measure for example flatness and roundness using the measurement perspective with different methods such as, best fit, 3 points or 6 points.

Possible Root Causes:

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

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