An Investment Casting Institute Publication

Atlas of Casting Defects

December 2017

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An Investment Casting Institute Publication

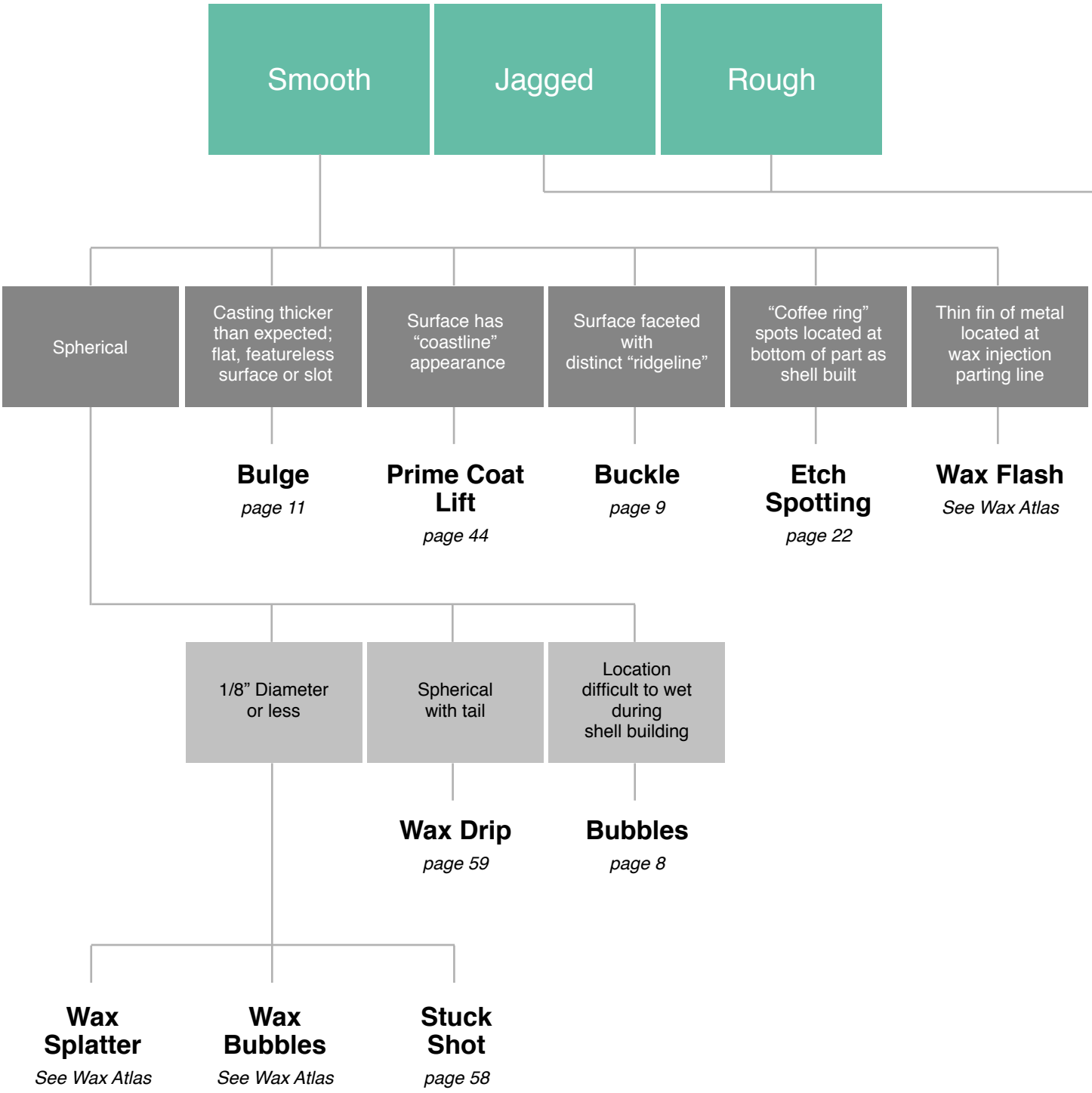
The Atlas of Casting Defects was updated and reformatted based on feedback from our members. This restructured Atlas combines the previous versions of the Atlas of Shell Defects and the Atlas of Casting Defects into a single publication. We have addressed all the potential causes of a casting defect broken down by Wax, Shell or Foundry. In addition, there is a new tool, the Defect Identifier, which can assist in pinpointing a particular defect. The only defects which are not included in this Atlas are wax defects that should be caught and corrected in the wax department. These defects are still covered in the Atlas of Wax Pattern Defects publication.

The ICI has also launched an on-line version of this publication which provides increased ease and flexibility thus reducing the time necessary to identify and resolve casting defects.

Acknowledgments

The Investment Casting Institute wishes to thank all of the members of the Institute's Publication Committee who provided information, photographs and valuable resources. The individuals on this committee worked hard to create this Atlas of Casting Defects. Without their support, time and effort, we would not be able to provide this valuable updated publication.

Defect Identifier: Positive



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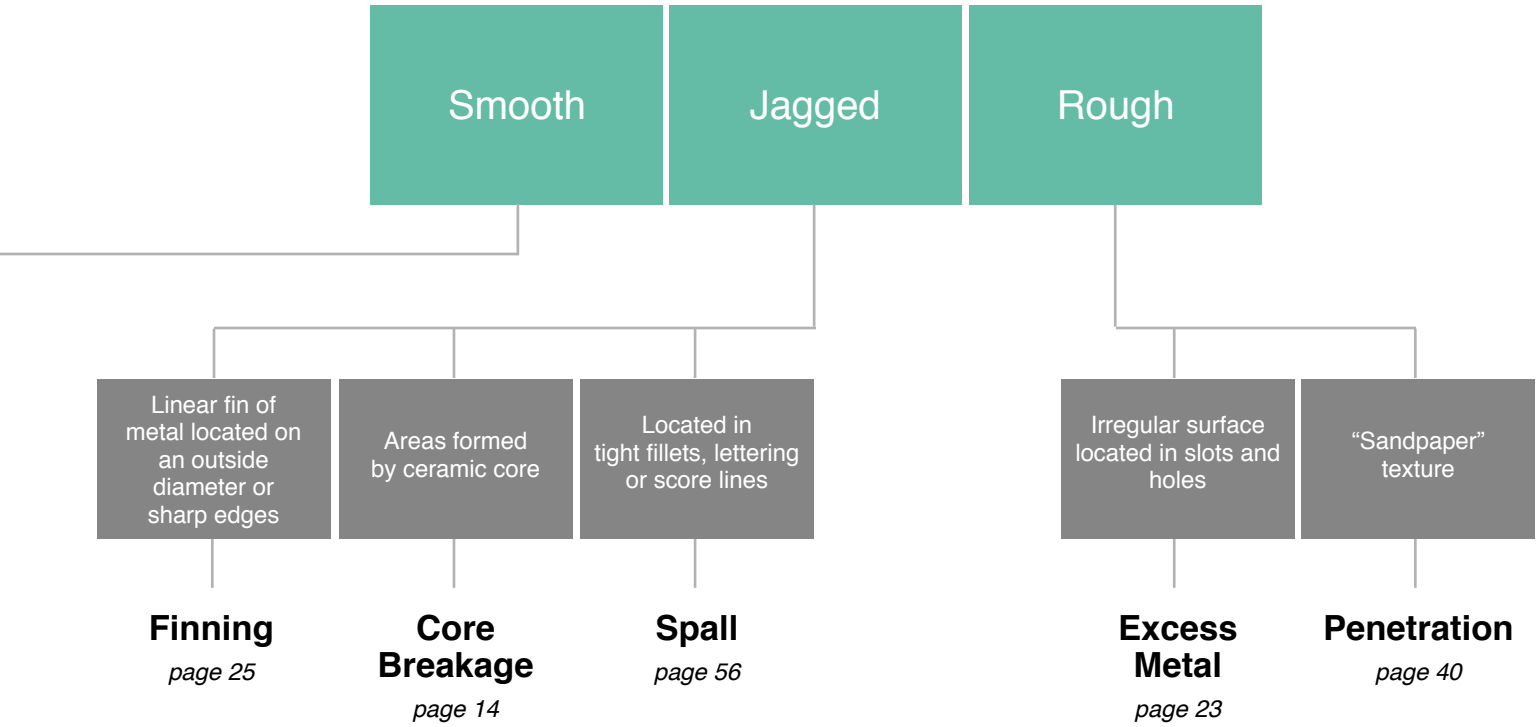
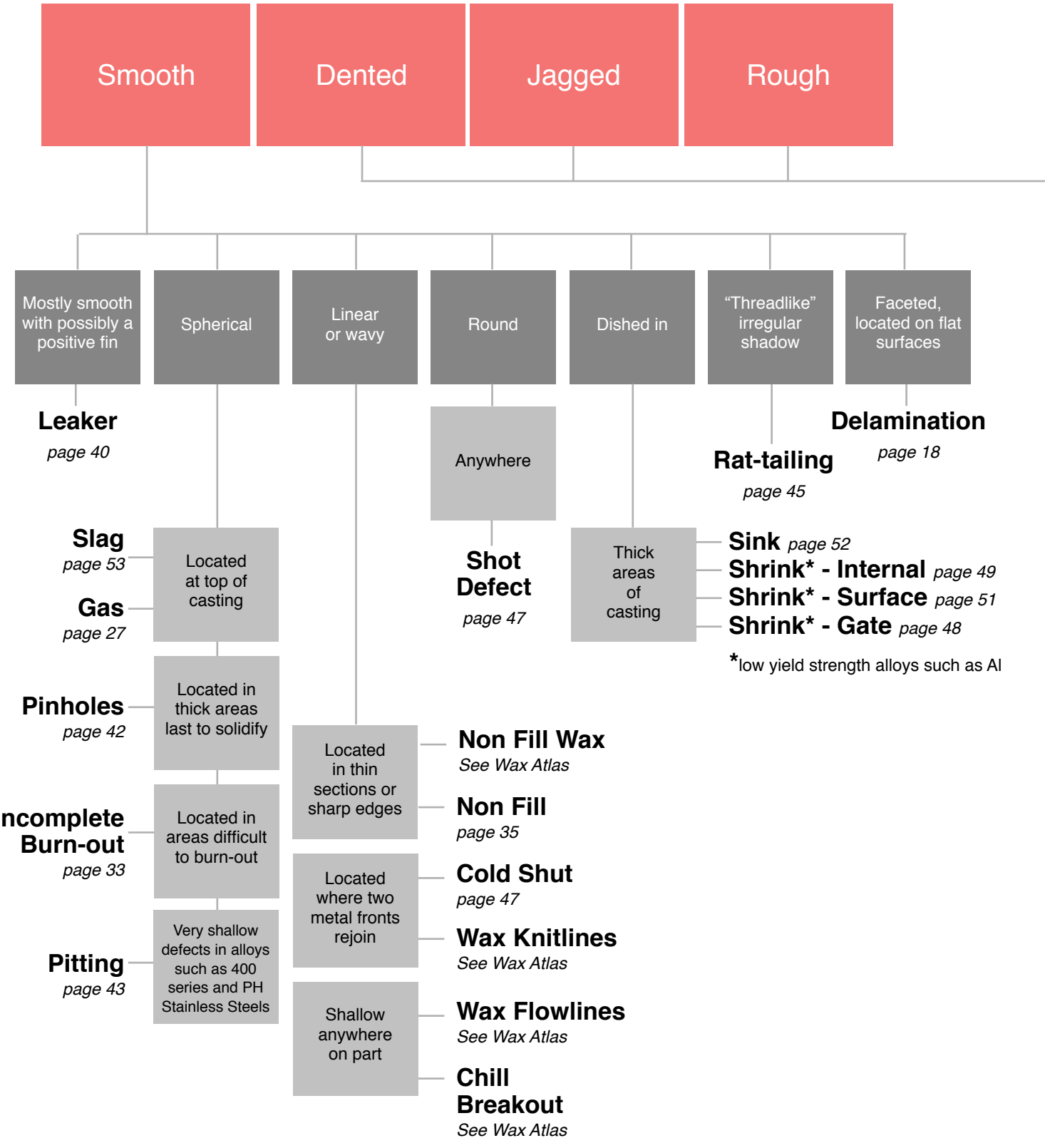


The information pertaining to this defect is available as part of the Wax Atlas. The Wax Atlas can be accessed at www.investmentcasting.org or ordered by contacting (201) 573-9770

Defect Identifier: Negative



Defect Identifier: Negative

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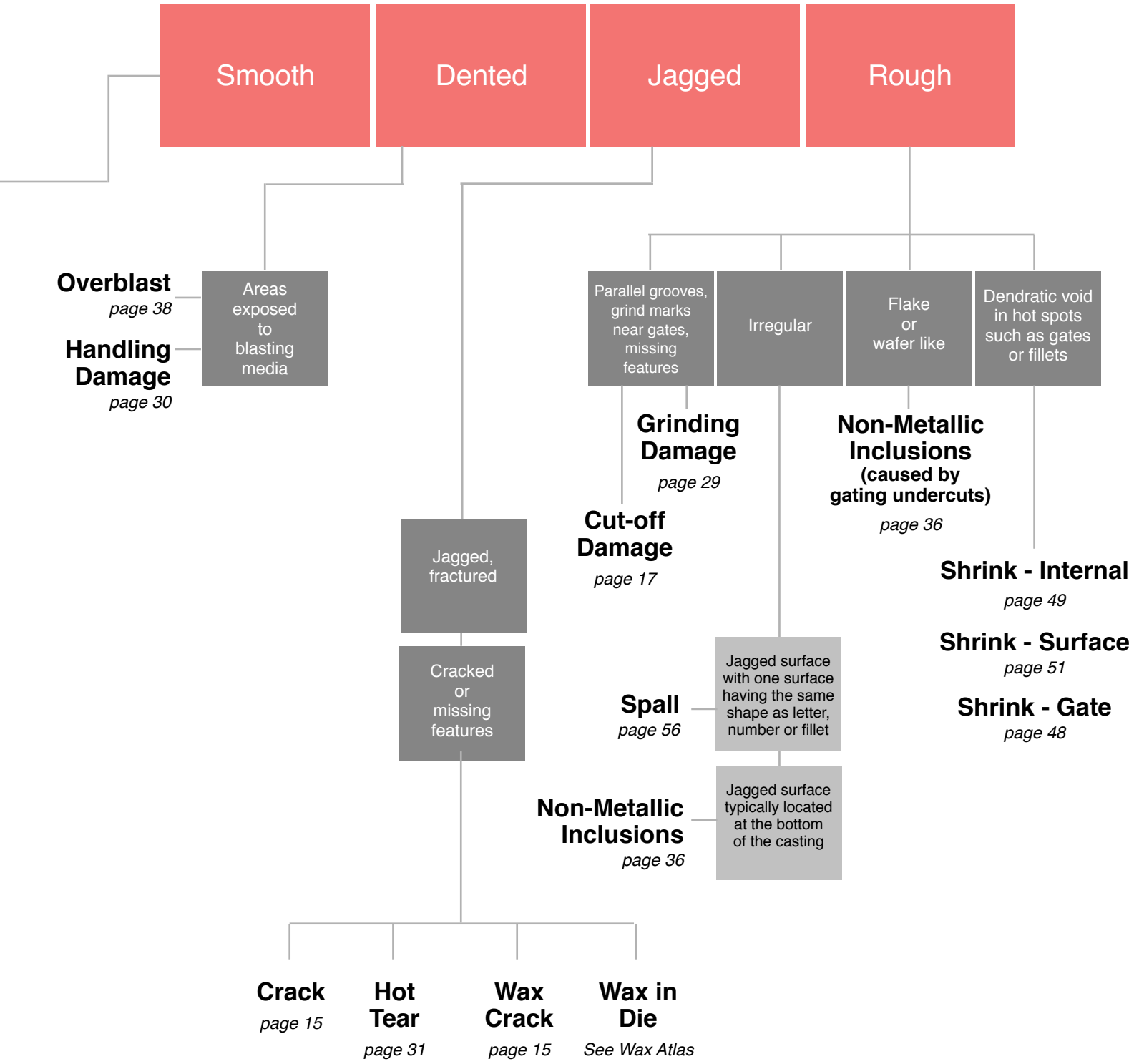

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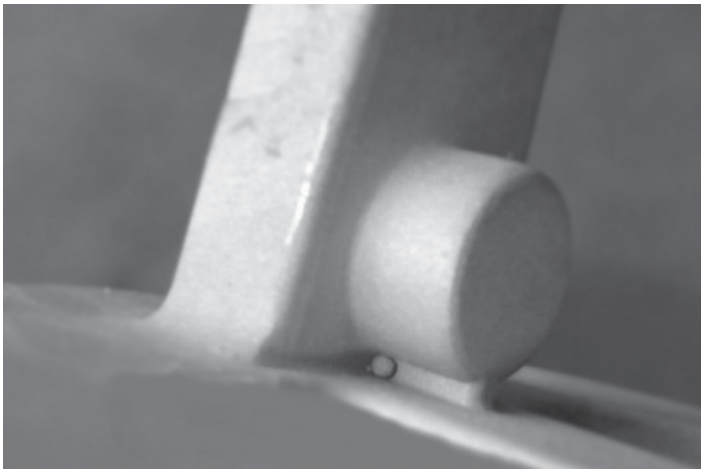
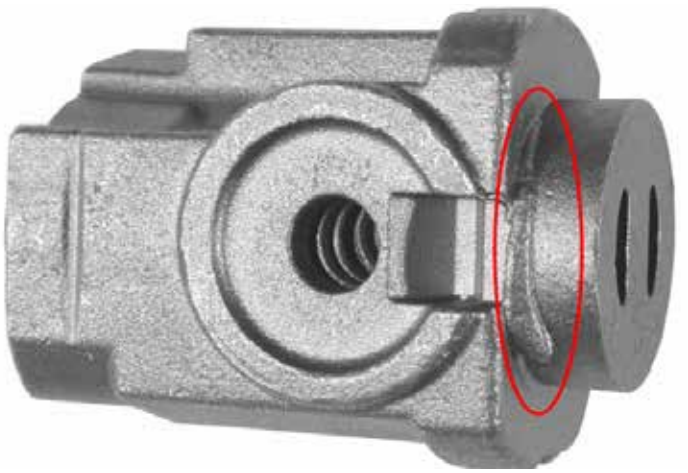
Bubbles





Mechanism

Air trapped against the wax pattern by the primary slurry layer

Description

Defect Type
Positive

Appearance
Small, smooth spherical, oval or elongated tubular shaped positive

Size
1/8” or less

Typical Location
Difficult to wet out areas during shell building

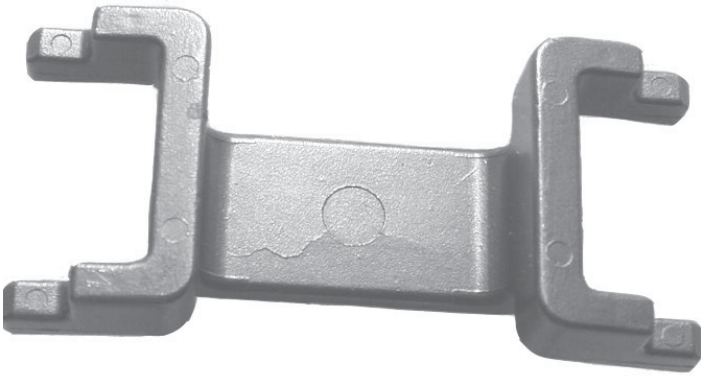
Similar to
Wax bubbles (see Atlas of Wax Pattern Defects), Stuck Shot

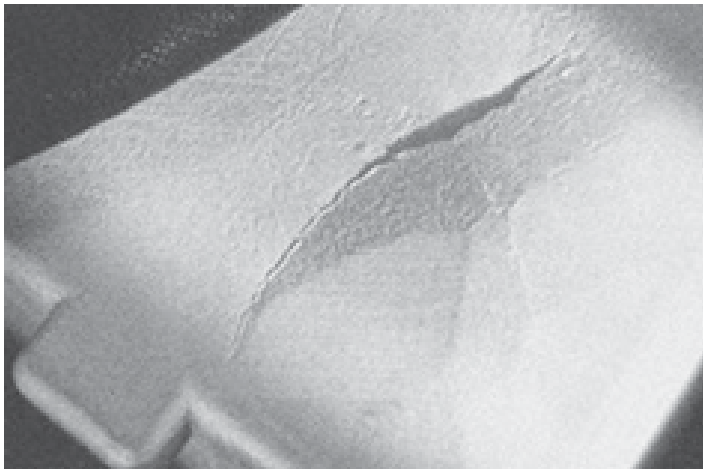
Aliases
BBs, Air Bubble

Method for defect determination
Visible to eye. Smooth surface of defect

Area	Possible Cause	Potential Correction
Wax	Bad mold design	Re-orient the part to prevent air from being trapped during dipping
Shell	Poor dipping technique	Immerse the pattern slowly in the slurry, use vibration or, compressed air or vacuum to pop any trapped air bubbles
Shell	Poor draining technique	Back drain slurry into areas that cannot be wet out during dipping
Shell	Incomplete pattern wetting	Use a pre-wet or use a lower prime coat viscosity
Shell	Insufficient slurry wetting	Insure the correct amount of wetting agent is in the slurry
Shell	Incomplete pattern cleaning	Insure the silicone is removed from all surfaces of the patterns and no air bubbles are preventing proper cleaning
Shell	High air level in the slurry	Insure air is not being sucked into the slurry by the mixer. Conduct antifoam test and adjust if necessary

Buckle





Mechanism

The bond strength of the primary layer to the wax patter is insufficient and the primary layer buckles (lifts) off the pattern. The bond strength can be insufficient for a number of reasons including stress on the primary layer as it shrinks during drying.

Description

Defect Type
Positive

Appearance
Faceted or pyramid like surface with a distinct ridgeline often associated with flash

Typical Location
Flat featureless surfaces

Similar to
Prime coat lift

Method for defect determination
When a shell buckles, it only separates from the pattern. With prime coat lift, the shell also fractures, allowing the backup layers to fill the gap between the primary layer and the wax pattern

Area	Possible Cause	Potential Correction
Wax	Temperature change in wax causes the wax to move and disrupt the primary layer bond. Wax pattern temperature not stable	Ensure the wax pattern has stabilized in temperature before applying shell layers
Wax	Pattern cleaning inadequate. Poor adhesion of the primary coat to the wax pattern	Increase etch strength or, time in etch. Reduce the time from etch to primary layer
Wax	Pattern flexing during dipping	Add additional pattern supports
Shell	Large temperature change	Control the dipping area to +/- 3 F
Shell	Drying too long	Set a maximum dry time
Shell	Drying too short	Insure the primary layer is completely dry before applying backup layers
Shell	Poor prime coat wetting	Confirm the prime slurry is wetting the pattern

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Buckle
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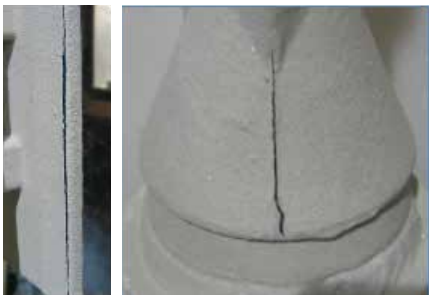

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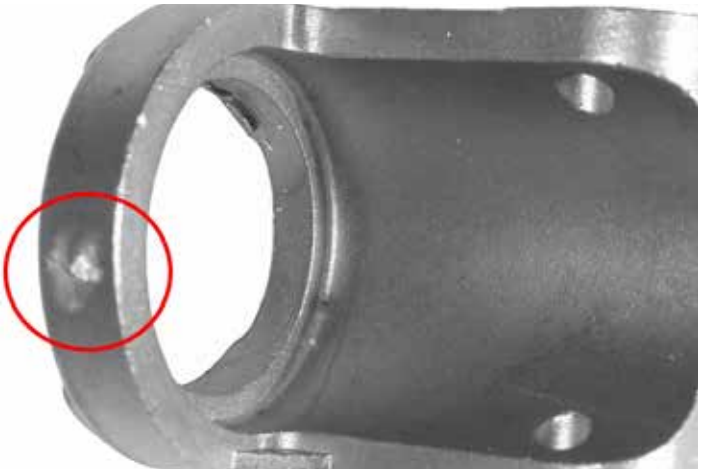
Area	Possible Cause	Potential Correction
Shell	Low adhesion binder	Increase polymer level
Shell	Drying too fast (high pattern shrinkage & drying stress)	Slow down (Increase) the drying by reducing airflow or increasing room humidity or reduce airflow
Shell	Pre-wet is lifting prime	Eliminate pre-wet or reduce dry time between pre-wet and slurry application
Shell	Too much slurry on interior surfaces	Decrease slurry viscosity or increase drain time
Shell	Too little slurry on interior surfaces	Increase slurry viscosity or decrease drain time
Shell	Insufficient stucco on interior surfaces	Don't let slurry surface dry or over drain before stucco application
Shell	Primary slurry in poor condition	Employ proper slurry controls
Shell	Soaking (saturating) the mold promotes lifting. Vibration too high	Vibration used during dipping can cause the primary coat to separate from the pattern
Shell	Pattern flexing during dipping	Add additional pattern supports
Shell	Soaking (saturating) the mold promotes lifting	Stucco molds immediately after slurry has drained
Shell	Thermal expansion mismatches within the shell	Change shell composition
Other (Mold design)	Pattern is too flat and featureless	Add ribs or dimples to break up flatness and create features
Other	Pattern flexing during dipping	Add additional pattern supports

Bulge



Mechanism

Permanent defection of the mold wall either during dewaxing or casting.

Description

Defect Type
Positive

Appearance
Gradual thickening of the casting wall. May have finning in the area of the bulge. May not be detectable by the naked eye but can be caught by gauging.

Typical Location
Parallel surfaces, deep holes, or slots. Adjacent patterns on assembly. Large flat featureless surfaces

Similar to
Similar in appearance to shell buckle but it doesn't have the definitive shape of a crack in the casting.

Aliases
Bulging, bulging cracking, bulging overheating, shell bulge

Method for defect determination
Shell bulge generally has a more rounded surface

Area	Possible Cause	Potential Correction
Wax	Patterns too close causing premature bridging	Use spacers during assembly to produce consistent pattern spacing
Shell	Shell too thin	Add shell layers or add stiffening feature
Shell	Mold hot strength too low (mold creeping during casting cooling)	1) Increase refractoriness of the shell 2) Ensure optimal SiO2 levels in the backup slurry 3) Ensure uniform mold thickness
Shell	Slurry not wetting out area	1) Use vacuum dipping or re-orient pattern. 2) Use a thinner slurry
Shell	Slurry/stucco not getting into area	Use a "poured core"
Shell	Stucco not getting into area	1) Rainfall, hand pour or re-orient pattern 2) If bridging in slots or holes, use a finer stucco or make sure hole is open prior to applying subsequent dips until sufficient slurry/stucco has been applied

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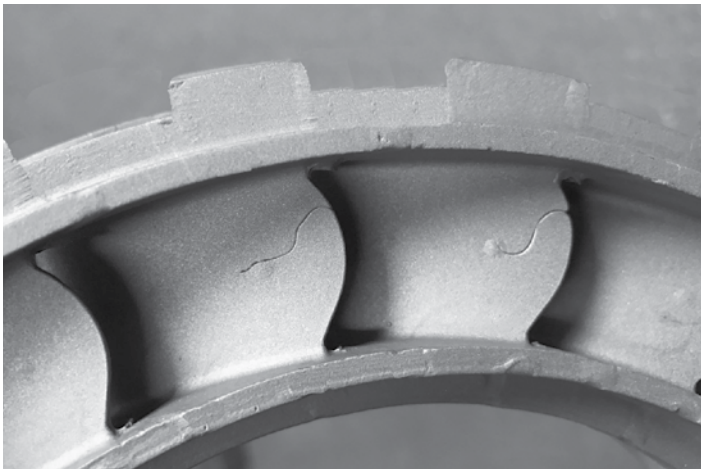
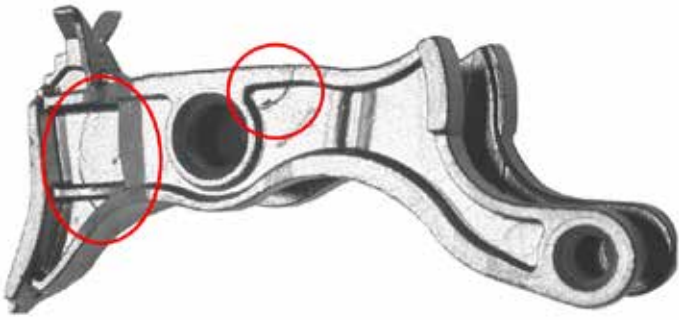
Area	Possible Cause	Potential Correction
Shell	Slurry is being washed away when subsequent coats are applied	Ensure sufficient intra-coat dry time and conditions for hard to dry areas of the mold
Shell	Green strength of the shell is too low to withstand dewaxing	1) Increase the dry time between each layer 2) Apply additional coats 3) Increase final dry time 4) Redesign assembly to permit a more rapid heat transfer to all parts of mold 5) Vent pattern cavities 6) Check dewax process for optimal performance and that it is in control
Shell	Deformation during dewaxing	See "Finning"
Foundry	Solidification time too long	Decrease metal temperature, decrease mold temperature, speed casting cooling rate
Foundry	Ferrostatic pressure too high	Reduce vacuum level, reduce spinning rate (centrifugal)
Foundry	Ferrostatic pressure too high	Reduce the metal height above the part

Cold Shut





Mechanism

Incomplete joining of two metal fronts

Description

Defect Type
Negative

Appearance
Smooth, linear, shallow, rounded edged impression extending into feature wall. This defect takes the form of a crack or discontinuity in the surface with rounded edges indicating the freezing or solidification of two or more streams of metal before they had time to completely fuse together.

Size
varies

Typical Location
Thin sections or areas furthest away from gate where two metal fronts meet.

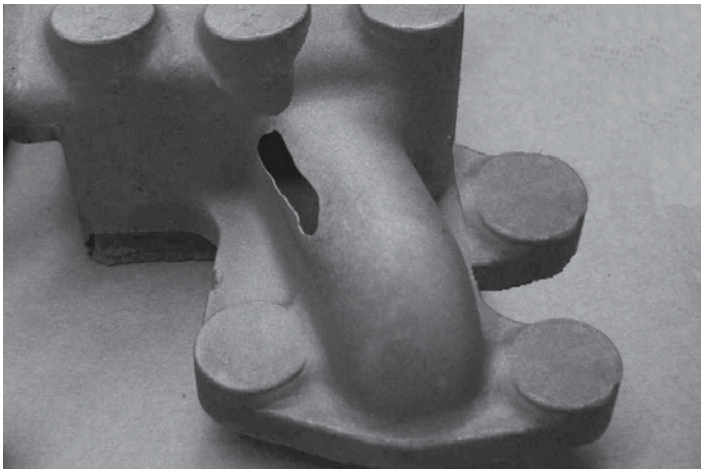
Similar to
Wax knitline (see Atlas of Wax Pattern Defects)

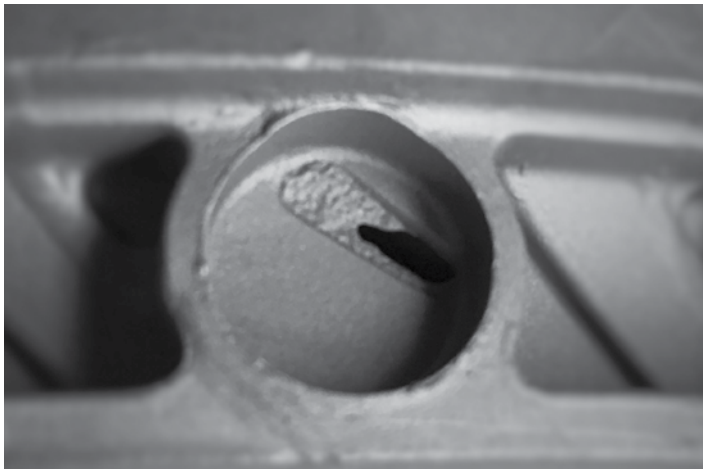
Aliases
Cold Shot, Short Fill

Method for defect determination
Penetrant inspection, visual inspection, metallographic inspection for evidence of non-bonding along line below cast surface. A wax knit line will have not extend below cast surface ceramic in the junction.

Area	Possible Cause	Potential Correction
Foundry	Metal not hot enough	Increase metal superheat
Foundry	Mold not hot enough	Increase mold temperature/ increase or add mold insulation
Foundry	For air cast, mold not permeable resulting in backpressure/trapping air that slows metal fill time	Reduce shell thickness or gating design to fill pattern cavity from more locations. Add vents. Increase shell permability
Foundry	Poor metal fluidity	Consider modifications to alloy composition
Foundry	Slow metal pour rate	Increase pour rate
Foundry	Interrupted pour	Maintain a steady pour rate until mold is full

Core Breakage





Mechanism

Core breaks either during wax injection, during mold heating, or metal pouring

Description

Defect Type
Negative

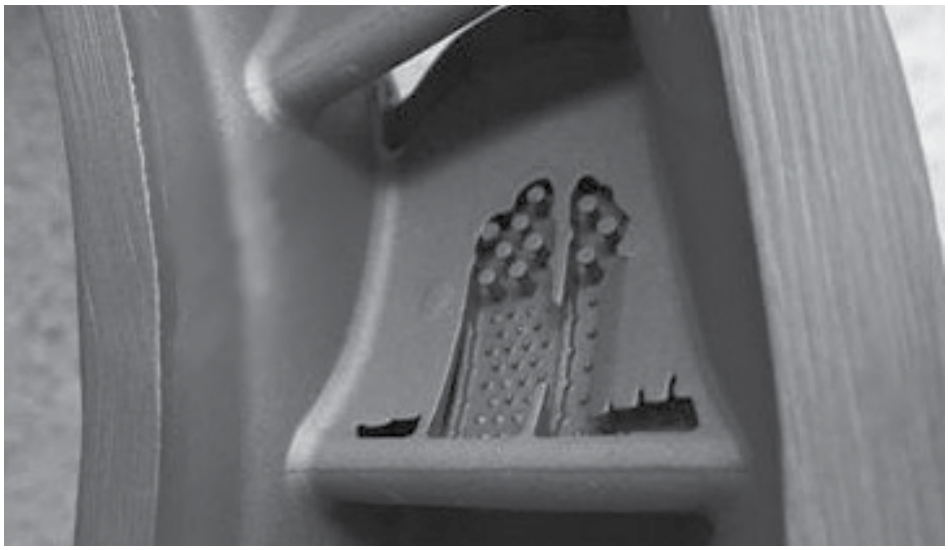
Appearance
Metal fin across an area that is formed by a ceramic core. In the case of core break and shift, missing metal where a wall should be.

Size
varies

Typical Location
Can only occur on casting made with ceramic core

Method for defect determination
Visual, X-ray in case of hidden from view

Area	Possible Cause	Potential Correction
Wax	Mold design creates stress on core upon clamping or wax injection	Examine need for core print relief or core supports to reduce stress
Shell	Poor core slipping method	Examine for too many core locks or “prints”
Other (Mold design)	Too high of wax injection pressure	Reduce injection pressure



Crack

Mechanism

Typically, internal stresses from solid-state cooling or rapid cooling can caused cracking.

Description

Defect Type
Negative

Appearance
Jagged crack with irregular path

Typical Location
Geometry involves seriously restrained contraction or in a local volume of unfed metal. May occur at the intersection of thick and thin section.

Similar to
Hot Tear

Method for defect determination
Visual inspection and Penetrant inspection typically reveal cracks. Cracks form roughly 90° to stress direction.

Area	Possible Cause	Potential Correction
Wax	Major sectional changes in the casting design	Modify gating to prevent strong gates or runners from preventing the casting from contracting
Wax	Restriction of casting contraction at elevated temperature	Modify the design to avoid contraction restriction and strengthen the weak areas by the use of webs
Foundry	Premature movement of mold after casting	Allow time for the casting to solidify before moving
Other (Post-cast operation)	Uneven cooling rate -The use of water to cool a hot casting can sets up high internal stress	Avoid rapid cooling methods
Other (Post-cast machining)	Removal of cast material can create an imbalance of the internal stress leading to cracking.	Add a stress-relief thermal cycle to as-cast part prior to metal removal operations
Other (Casting design)	Restriction of casting contraction at elevated temperature	Modify the design to avoid contraction restriction and strengthen the weak areas by the use of webs

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Crack
continued

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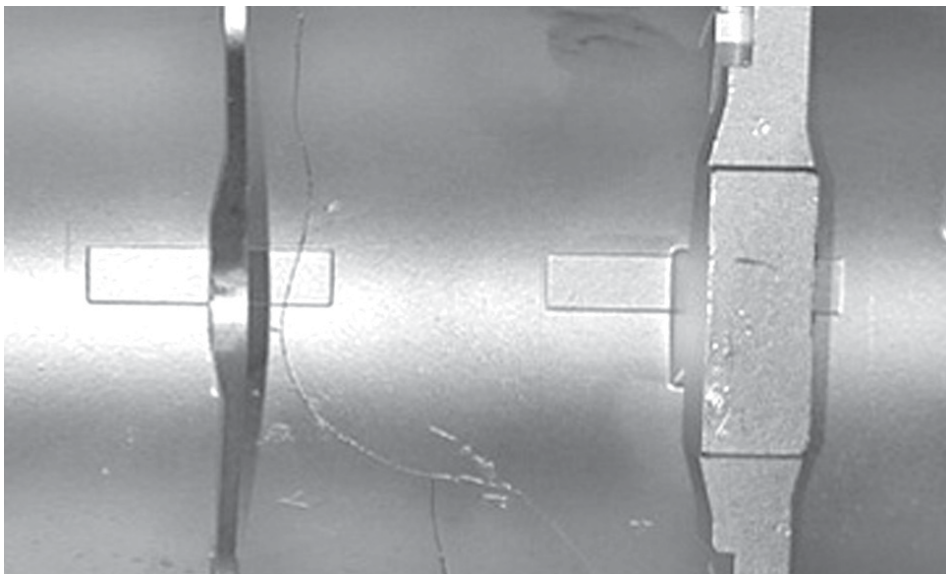
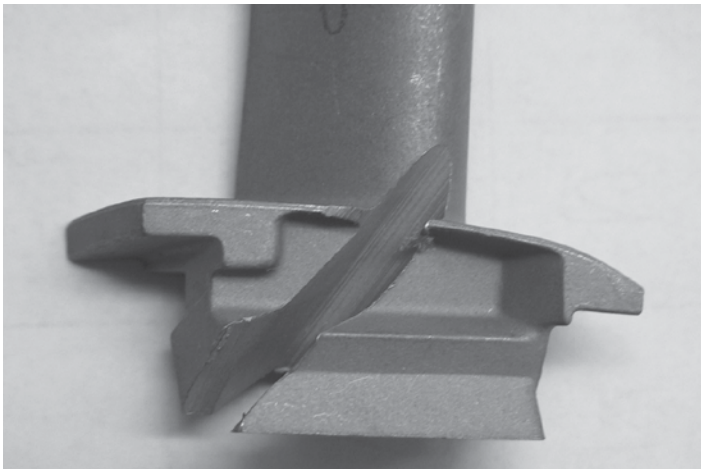
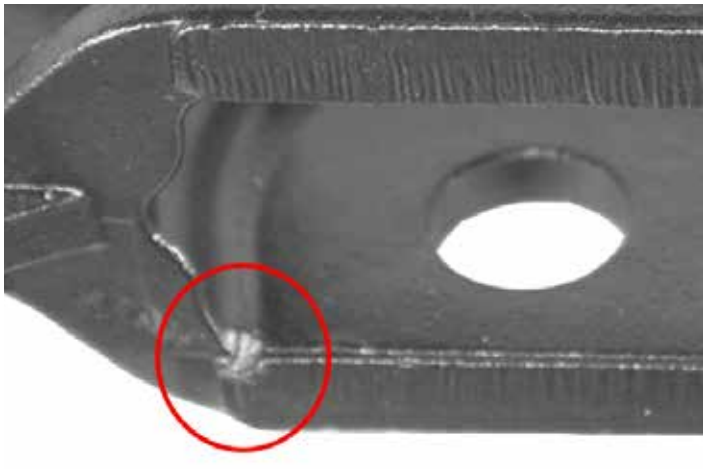
Area	Possible Cause	Potential Correction
Other (Casting design)	Major sectional changes in the casting design	Modify gating to prevent strong gates or runners from preventing the casting from contracting
Other (Casting design)	Sharp internal angles	Ensure adequate fillet radii



Cut-off Damage





Mechanism

Blade or plasma torch deflects into casting or continues into casting after cut

Description

Defect Type
Negative

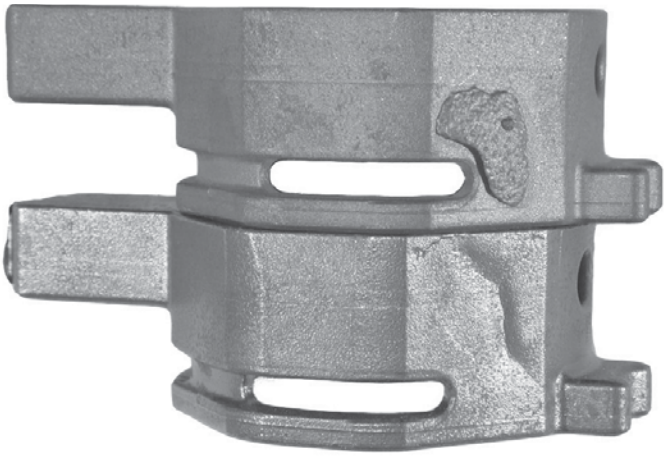
Appearance
Slot or beveled face with characteristic grooves running the direction of the cut-off wheel

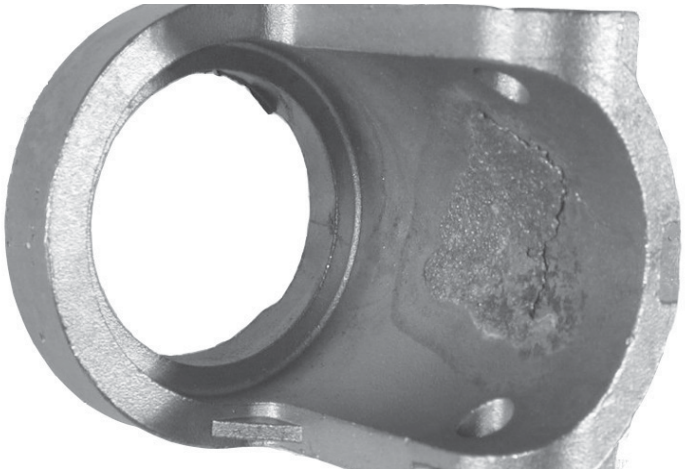
Typical Location
Anywhere but typically near a gate contact

Method for defect determination
Visual inspection

Area	Possible Cause	Potential Correction
Other (Gating Design)	Castings too close to the runner bar/ variable distance from runner bar	Increase gate length
Other (Post-Cast operation)	Incorrect part loading in cutoff fixture	Mistake proof the holding fixture
Other (Post-Cast operation)	Cut-off blade flex during the cut-off	Use different blade, change gate shape

Delamination





Mechanism

Failure of bond between 1st and 2nd layer of shell. The first layer is pushed or pulled into the mold cavity usually during dewax. Sometimes the shell cracks and metal fills the gap between the layers producing a scab.

Description

Defect Type
Negative

Appearance
Faceted metal indentation sometimes accompanied by a positive metal scab

Typical Location
Flat featureless surfaces

Aliases
Scabbing, Reverse Buckle

Method for defect determination
Visual, appears as scab with indentation under scab

Area	Possible Cause	Potential Correction
Shell	Incomplete wetting between 1st and 2nd layer	Blow off loose primary coat stucco. Ensure immersion time in 2nd layer slurry is adequate to wet-out the primary layer
Shell	Etch too strong – too tacky	Reduce etch strength or time
Shell	Drying rate of 2nd layer too high	Increase drying room humidity
Shell	Poor bond between prime and backup layer	Ensure adequate keying between the primary and first backup coat. Use a coarser or more angular primary coat stucco blow off loose or excess stucco
Shell	Moisture trapped behind the primary coat	Ensure adequate drying of the mold prior to dewaxing
Shell	Differential expansion stresses between the primary and secondary coats	Ensure the thermal expansion of the primary coat is compatible with that of the shell coats
Shell	Rapid pressure release during autoclave dewaxing	Autoclave blowdown should be gradual and take 2 minutes or more

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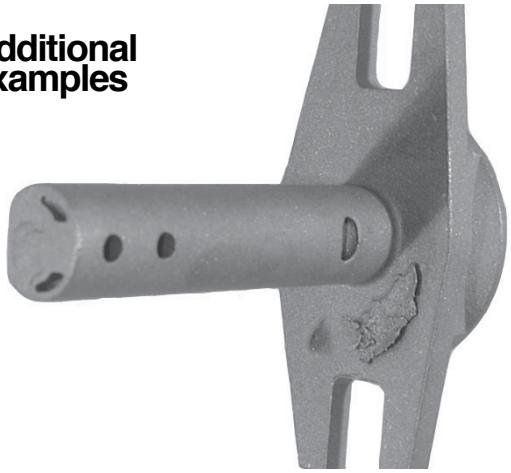
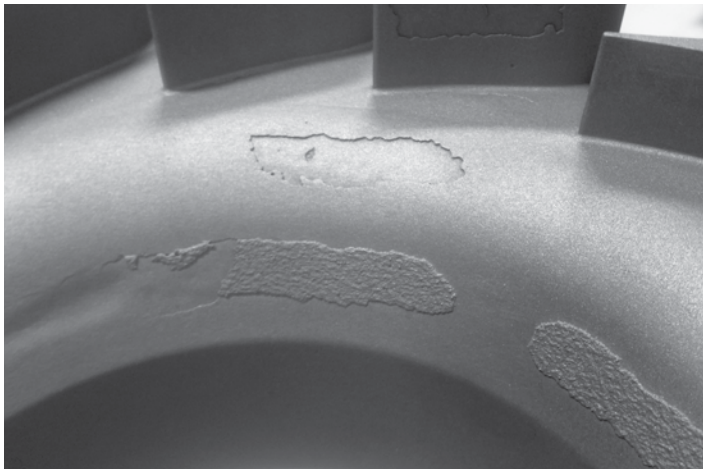
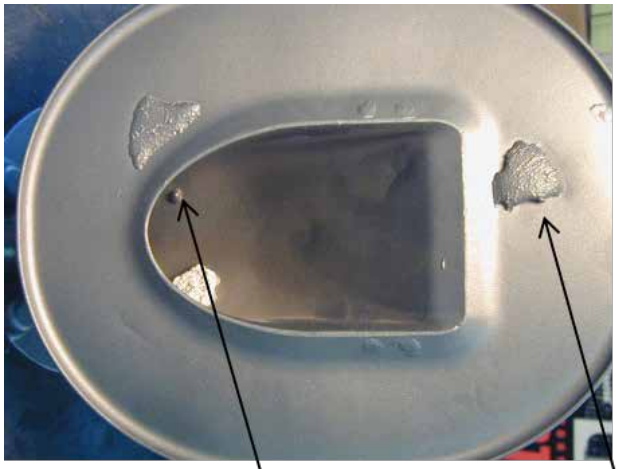
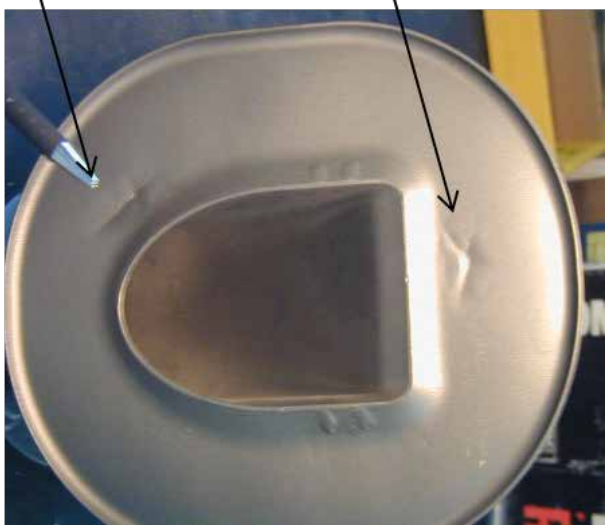
Delamination

Additional examples









Distortion

Figure 1
Raised pads are witness to gating locations on the outside of the tube casting.

Figure 2
Depressions on the interior of the tube are created during the casting process.

Mechanism

Distortion of the casting occurring at wax injection, pattern assembly, or casting cooling.

Description

Defect Type
Shape

Appearance
The geometry does not conform to the drawing

Size
varies

Typical Location
Opposite gate locations

Similar to
Sink, Cavitation (See Atlas of Wax Pattern Defects)

Method for defect determination
Visual inspections and customary dimensional inspection tools

Area	Possible Cause	Potential Correction
Other (Casting design)	Geometry of the casting and or running system causing uneven contraction	Minimize uneven stresses that develop with solid-state metal contraction occurs
Other (Mold design)	Improper gating system design	Design the gating and runner system to prevent uneven stresses
Other (Mold design)	Ingates contracting and pulling part of the casting	Examine the runner system and modify to reduce stresses
Wax	Improper wax pattern handling ejected from die	Modify release agent spraying technique, frequency. Add ejector pins
Wax	Improper wax pattern storage	Store patterns in a manner to prevent distortion
Wax	Ingates contracting and pulling part of the casting	Examine the runner system and modify to reduce stresses
Wax	Improper gating system design	Design the gating and runner system to prevent distortion

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Distortion

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Area	Possible Cause	Potential Correction
Shell	High strength mold preventing even contraction	Reduce the mold strength
Other	Knockout conducted at too high a temperature	Knockout at a lower temperature
Foundry	Improper casting handling	Ensure cast molds are handled with care – especially at high temperature
Other (Heat treatment)	Stresses induced during heat treatment	Ensure the castings are correctly supported during heat treatment. Use the slowest quenching method that will achieve the required hardness

Etch Spotting

Mechanism

During pattern cleaning prior to shell building, the etch solution is not completely rinsed off. The etch continues to attack the wax forming rings or drips on the bottom of the pattern

Description

Defect Type
Negative and Positive

Appearance
Smooth. Raised droplet or "coffee ring" like appearance where ring may be slightly indented into casting

Special Circumstances
Most common with difficult to rinse etch solutions

Size
¼" or less

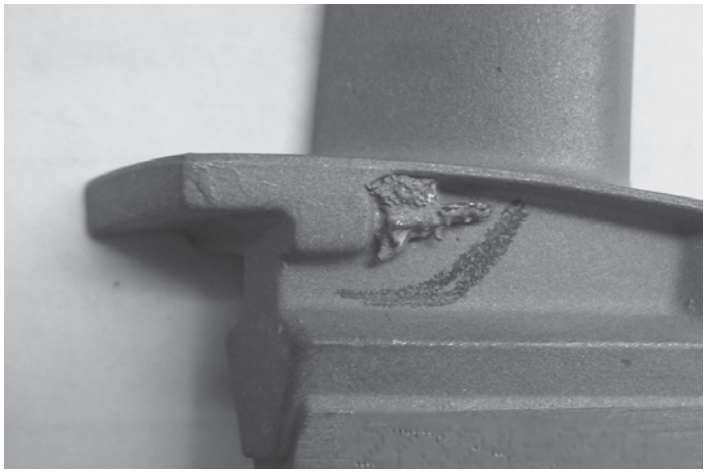
Typical Location
End of part away from the pour cup. Areas where etch rinse water beads up after pattern cleaning or there is insufficient rinse action on the surface of wax. Often in deep corners but can occur on open surfaces.

Aliases
Fisheyes

Method for defect determination
Monitor the etching operation and inspect wax patterns prior to first dip in pre-wet or primary dip

Area	Possible Cause	Potential Correction
Shell	Incomplete rinse after pattern etch	Increase agitation during rinse, keep rinse water clean and/or use multiple rinse tanks. Last rinse water should always be clear to ensure cleanliness. Make sure water temperature is room temperature.
Shell	Incorrect etch concentration	Some etch products require mixing with water prior to use. Verify measurements and test concentration if possible.

Excess Metal



Mechanism

Thin or weak areas of the shell fail during dewax or casting allowing metal to leak into the void in the shell.

Description

Defect Type
Positive

Appearance
Irregular shaped mass typically attached to the casting by flash

Size
Varies but typically metal is re-strained by external shell geometry

Typical Location
Holes, slots, or tight corners

Aliases
Metal breakthrough,
Metal Penetration,
Core Collapse

Method for defect determination
Visual Inspection

Area	Possible Cause	Potential Correction
Other (Mold design)	Poor mold design	Re-orient the part to improve slurry and stucco coverage
Shell	Poor shell build / slurry / stucco schedule	Improve wetting of detail by shell code changes, re-orienting the part or vacuum dipping, thinner slurries and finer stuccos, use intermediate slurry and or stucco
Shell	Incomplete loose stucco removal	Blow loose stucco out of detail, slots or blind holes
Shell	Incomplete slurry wetting	Change pattern orientation, use vacuum dipping, lower the slurry viscosity or use prewet solutions
Shell	Incomplete drying	Increase the dry time between layers
Shell	Incomplete stucco coverage	Pour stucco into the area, change orientation of the pattern, use finer or intermediate stucco
Shell	Stucco too large	Change shell code, use finer stucco

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Excess Metal

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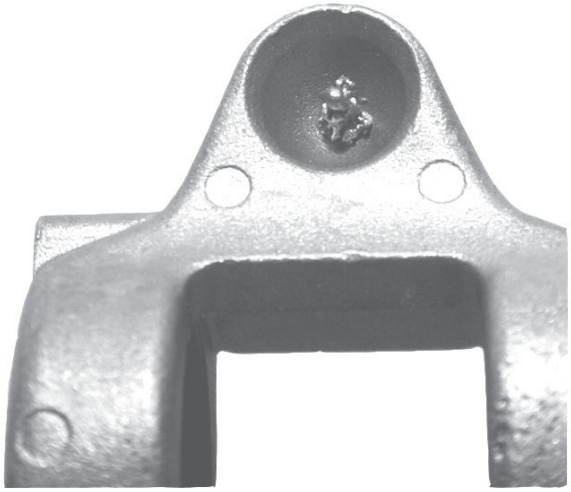
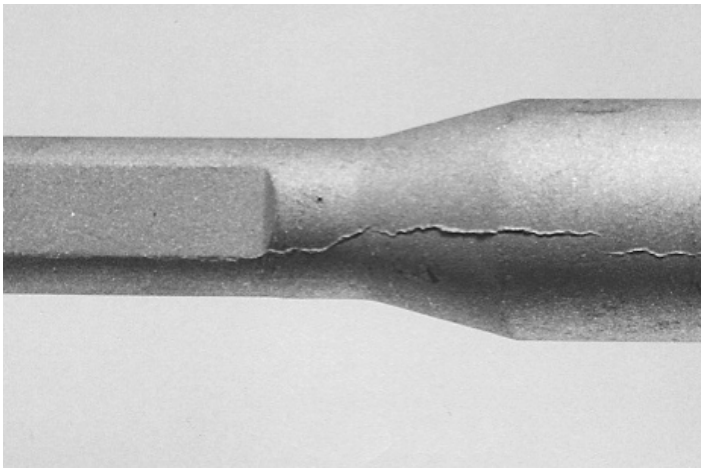
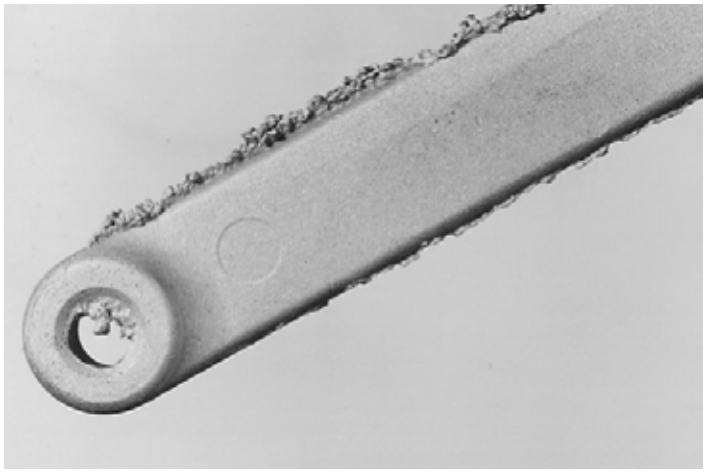
Area	Possible Cause	Potential Correction
Shell	Stucco contains large particles (“rice krispies” or “snerds”)	Sift the large particles out of the stucco
Shell	Dewax cracking	Improve dewax performance
Shell	Autoclave depressurization too rapid	Gradually depressurize the autoclave over 2 minutes or more
Other (Casting design)	The core length to cross-sectional area too great to allow production of a sound core by normal shell techniques	Form area with “poured core” or preformed ceramic core



Finning





Mechanism

Shell crack during shell building, drying or dewaxing, and molten metal fills the crack during casting. Cylindrical shapes are more prone to this defect due to hoop stress

Description

Defect Type
Positive

Appearance
Sharp, linear fin of metal perpendicular to the surface

Typical Location
Flat featureless surfaces, sharp edges or cylindrical parts, across holes

Similar to
Wax flash (See Atlas of Wax Pattern Defects)

Aliases
Flash,
Shell Crack,
Mold Crack

Method for defect determination
Wax flash can only be located on the parting line of the pattern

Area	Possible Cause	Potential Correction
Wax	Runner wax melts too slow creating increased pressure by part wax on mold as it melts	Change the formulation of the runner wax to insure it melts as fast or faster than the pattern wax, use a low melting point wax to apply “dip seal” to the runner system
Wax	Pattern wax does not bleed through the mold during dewaxing	Change pattern wax or increase green permeability
Wax	Wax flash / parting line not removed	Removal all parting line indications
Shell	Low mold strength	Add an additional shell layer, use a polymer, increase SiO2 of slurry
Shell	Incomplete mold drying	Increase the mold dry time
Shell	Slow autoclave pressurization	The autoclave should rapidly pressurize to 80 psi in 10 seconds or less
Shell	Large temperature fluctuations during drying	Maintain 3F maximum temperature variation

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Finning

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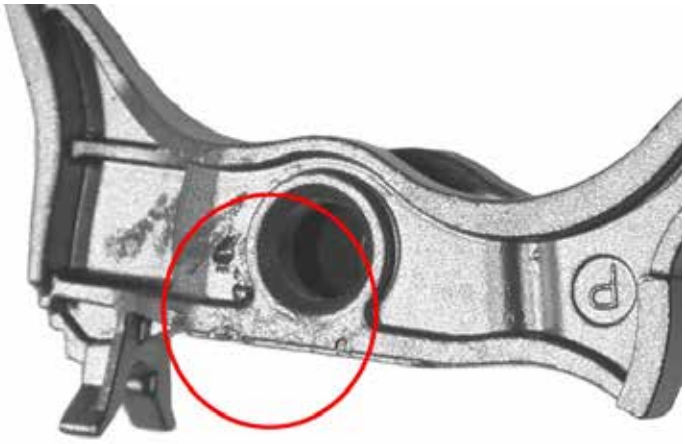
Area	Possible Cause	Potential Correction
Shell	Inadequate dewax pressure relief	Add venting to difficult to dewax areas
Shell	Slow dewax loading	Load dewax unit quickly to reduce mold exposure to heat
Shell	Pattern wax does not bleed through the mold during dewaxing	Change pattern wax or increase the shell permeability

Gas



Mechanism

During casting, turbulent flow mixes the air that is exiting the mold with the metal that is entering. These bubbles float to the surface of the metal but are trapped by the solidifying metal. (Like air bubbles trapped under a layer of ice). This also can be caused by incomplete burnout of the wax and filler material in the mold, igniting when the molten metal reaches this material. Gas defects can also be formed when ceramic cores out-gas, or the strengthening materials (such as binders or superglue) applied to cores, burns out (usually associated with low preheat temperatures). Low permeability of molds is another cause of entrapped gas.

Description

Defect Type
Negative

Appearance
Round smooth walled cavities which may exhibit a slightly oxidized surface of varying diameter

Size
0.5 to 4 mm

continued on next page

Area	Possible Cause	Potential Correction
Other (Mold design)	Poor gating design	Add vent at top of part to allow air to escape
Other (Mold design)	Poor gating design	Modify gating system to prevent turbulence during metal filling
Other (Mold design)	Low ferrostatic pressure	Increase the height of the mold, use vacuum assistance, centrifuge
Shell	Low mold permeability	Increase the mold permeability or use vacuum assistance during pouring
Foundry	Bad pouring practice	Reduce height from ladle to mold, pour down the side of the pour cup
Foundry	Excessively turbulent metal flow into the mold. Low ferrostatic pressure	Modify the gating technique to give less turbulent flow; self-venting mold. Increase the height of the mold, use vacuum assistance, centrifuge
Foundry	Low metal temperature	Increasing the metal temperature allows more time for gas bubbles to escape before a skin is formed

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Gas

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Typical Location
Generally located on the upper region of the part as-cast

Similar to
Pinholes, Blowholes, Slag, Incomplete Burn-out

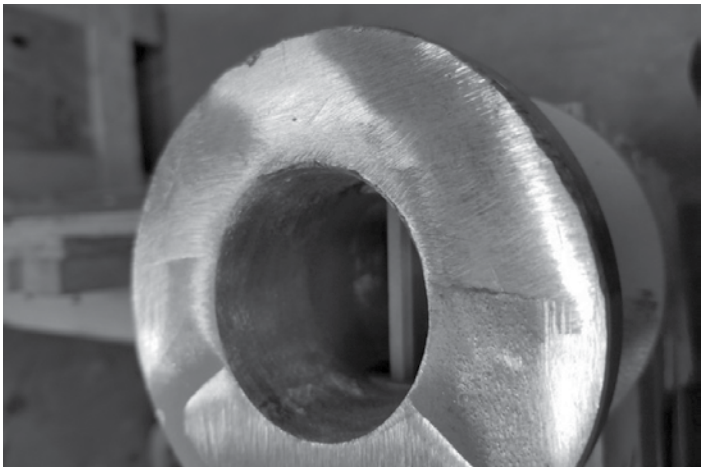
Aliases
Entrapped Air, Porosity

Method for defect determination
Upper region of the part as-cast, only a few holes. Fewer number of cavities than pinholes

continued from previous page

Area	Possible Cause	Potential Correction
Foundry	Excess wax and Filler material after dewaxing mold	Burn molds out fully prior to preheat. Add excess oxygen to preheat/ burnout oven to ensure complete burnout of mold.
Foundry	Poor deoxidation practices	Improve practices
Foundry	Moisture contained within the metal feedstock	Ensure metal is free from moisture rust or lubricants. Ensure ladles are cured and dry before use.

Grinding Damage



Mechanism

Abrasive grinding belt or wheel continues grinding into casting after removing the gate

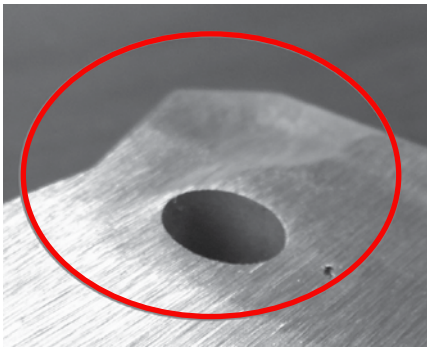
Description

Defect Type
Negative

Appearance
Missing features or low wall thickness with linear serrations

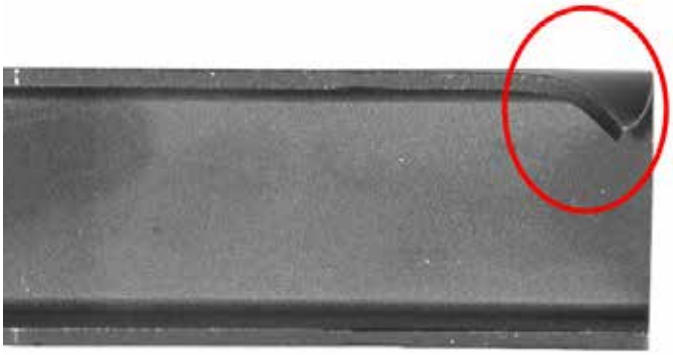
Typical Location
Near gates or on same surface as gates

Similar to
Cutoff Damage



Area	Possible Cause	Potential Correction
Other	Grind depth set too deep	Ensure grinding depth set correctly on automatic grinder
Other	Part improperly loaded	Mistake proof part loading on the grind fixture
Other	Residual ceramic prevents proper fixture loading	Improve ceramic removal method
Other	Incorrect belt width	The contact wheel and grinding belt should be sized according to the gate width
Other	Snagging from loose grip in operator's hand	Hold casting tight in hand when approaching belt or disc
Other	Excess Snagging from inability to see grind area interface	Change view angle
Other	Incorrect grit size on belt	Ensure belt grit size before grinding

Handling Damage



Mechanism

Castings are damaged at some point after solidification

Description

Defect Type
Negative and positive

Appearance
Dinged surface. Smooth negative with accompanying positive burr, dented edge, rolled corner, bent or distorted metal

Size
Various

Typical Location
Protruding features, corners, thin areas

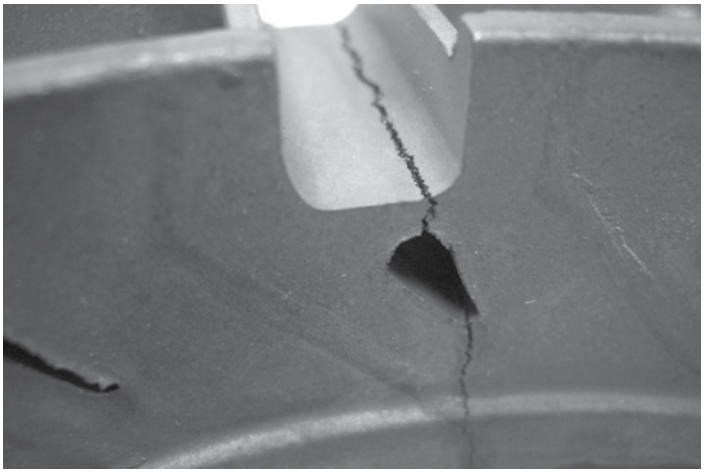
Similar to
Wax damage (See Atlas of Wax Pattern Defects)

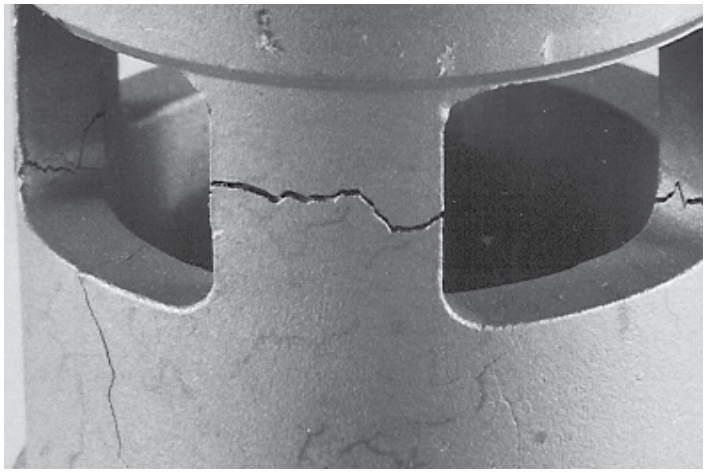
Aliases
Knockout Damage

Method for defect determination
Visual or dimensional gauging

Area	Possible Cause	Potential Correction
Foundry	Damage occurring during handling	Prevent operators from dropping castings onto one another
Other (Knockout/ cutoff/blasting)	Damage occurring during mechanical cleaning	Reduce tumbling speed or add cushioning material with castings (addition of rubber blocks during tumble blast)
Other (Transporting)	Damage occurring during transportation	Ensure floors are level, wheels on carts are adequate

Hot Tear





Mechanism

During casting cooling, the strength of the shell or gating system exceeds that of the solidifying metal

Description

Defect Type
Negative

Appearance
Jagged crack with irregular path, typically with an oxidized fracture face

Typical Location
Slow to cool or solidify areas where the geometry involves seriously restrained contraction or in a local volume of unfed metal. May occur at the intersection of thick and thin section.

Similar to
Crack, Wax Crack (See Atlas of Wax Pattern Defects)

Aliases
Shrinkage Crack

Method for defect determination
A wax crack will typically contain refractory and have a somewhat smooth, non-dendritic fracture face

Area	Possible Cause	Potential Correction
Wax	Restriction of casting contraction at elevated temperature	Modify the design to avoid contraction restriction and strengthen the weak areas by the use of webs.
Wax	Major sectional changes in the casting design	Modify gating to prevent strong gates or runners from preventing the casting from contracting
Shell	Sharp internal angles	Ensure adequate fillet radii
Shell	Gating incorrect	Reduce the mold strength. Modify gating to prevent strong gates or runners from preventing the casting from contracting Use a slower cooling rate
Shell	Shell too strong	Reduce shell layers. Allow time for the casting to solidify before moving
Foundry	Premature movement of mold after casting	Allow time for the casting to solidify before moving
Foundry	Uneven cooling rate	Sink mold after casting or wrap in insulation

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Area	Possible Cause	Potential Correction
Foundry	Gating incorrect	Reduce the mold strength. Modify gating to prevent strong gates or runners from preventing the casting from contracting Use a slower cooling rate
Foundry	Metal chemistry	Use certified virgin ingots
Foundry	Metal chemistry	Modify the metal chemistry
Other (Mold design)	Gating incorrect	Reduce the mold strength. Modify gating to prevent strong gates or runners from preventing the casting from contracting Use a slower cooling rate
Other (Casting design)	Sharp internal angles	Ensure adequate fillet radii
Other (Casting design)	Casting design	Modify the casting design where possible to reduce major sectional changes
Other (Mold Design)	Restriction of casting contraction at elevated temperature	Modify the design to avoid contraction restriction and strengthen the weak areas by the use of webs.
Other (Casting design)	Major sectional changes in the casting design	Modify gating to prevent strong gates or runners from preventing the casting from contracting

Incomplete Burn-out

Mechanism

During casting, residual carbon in the mold remaining from incomplete burnout react with molten metal producing CO. The CO, in the form of a gas bubble, prevents the metal from filling the area

Description

Defect Type
Negative

Appearance
Smooth irregular shaped voids generally in or just under the cast surface usually irregular in outline but tending to assume a spherical or wormlike shape. The casting surface may exhibit a matte finish in the area of the defect

Size
1 to 4 mm

Typical Location
Sections of mold that don't drain during dewax. Areas of mold that are densely packed when shell built.

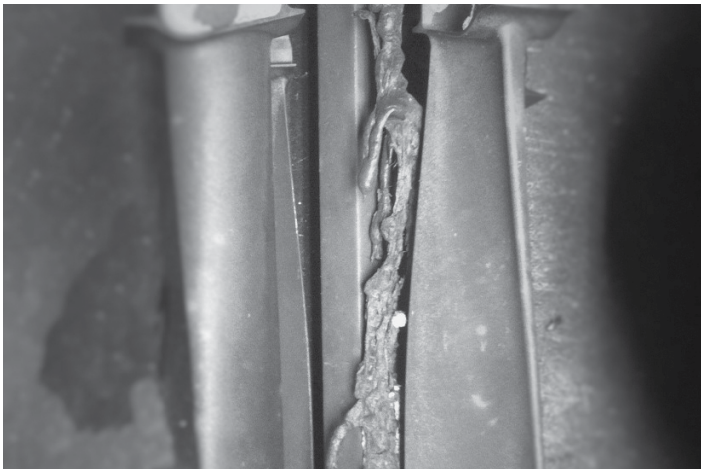
Similar to
Gas, Slag

Alias
Ash

Method for defect determination
Gas tends to be on the upper surface or the part during casting. Metal mold reaction is located where the carbon does not burn out

Area	Possible Cause	Potential Correction
Other (Mold design)	Poor wax drainage	Orient the parts to allow for a high level of wax drainage from the mold
Other (Mold design)	Patterns too close	Increase spacing between patterns to prevent shell bridging
Wax	Patterns too close	Increase spacing between patterns to prevent shell bridging
Wax	High ask content in wax	Use a low ash content wax
Shell	Incomplete wax removal	Insure the dewax cycle time is adequate to remove all of the wax
Foundry	Short mold burn-out time	Increase burnout time
Foundry	Insufficient air circulation in the mold	Place molds on stand or ribbed hearth plate
Foundry	Low oxygen level in the burnout furnace	Increase excess air
Foundry	Contamination of the mold	Rinse mold and/or cover pour cup to prevent contamination

Leaker



Mechanism

Metal leaks out of the mold during or immediately after casting

Description

Defect Type
Negative

Appearance
Smooth in most instances, but also be rough. It could be irregular. Many features or runners missing because of lack of metal. May have a positive fin where the leaker occurred.

Typical Location
Top of casting as oriented during casting

Aliases
Runout,
Short Pour

Method for defect determination
Visual inspection

Area	Possible Cause	Potential Correction
Wax	Handling damage	Examine process and add preventive measures
Shell	Broken shell – handling damage.	Improve dewaxing performance or dip molds after dewaxing, mold handling to prevent damage to the mold
Shell	Low mold strength	Verify slurry in spec and control or add shell layers
Shell	Dewax cracking	Fill mold with colored dye/ water mix to identify crack locations. Add wax vents. Improve dewaxing performance
Shell	Poor patch coverage– incomplete drying	Modify patching procedure to insure complete drying prior to placing in burnout oven
Shell	Handling damage	Examine process and add preventive measures
Foundry	Rough handling of hot mold	Examine process and add preventive measures
Foundry	Handling damage	Examine process and add preventive measures

Non Fill

Mechanism

During casting, the metal freezes before mold cavity is completely filled out

Description

Defect Type
Negative

Appearance
Incomplete casting with rounded edges where casting is not completely formed

Typical Location
Thin sections and sharp edges away from the gate

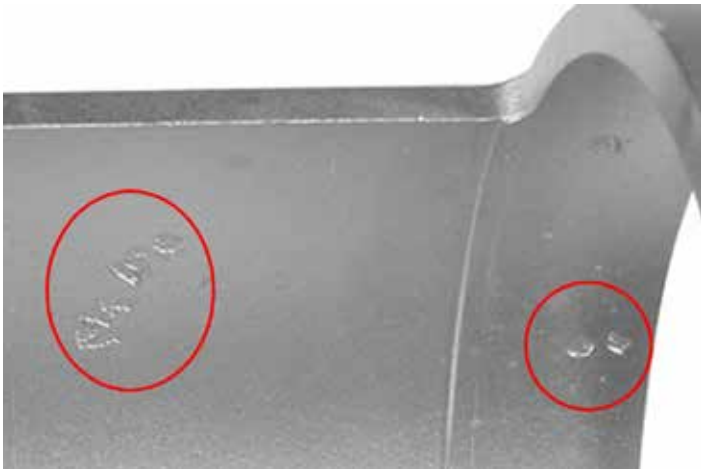
Similar to
Cold Shut, Wax non fill (See Atlas of Wax Pattern Defects)

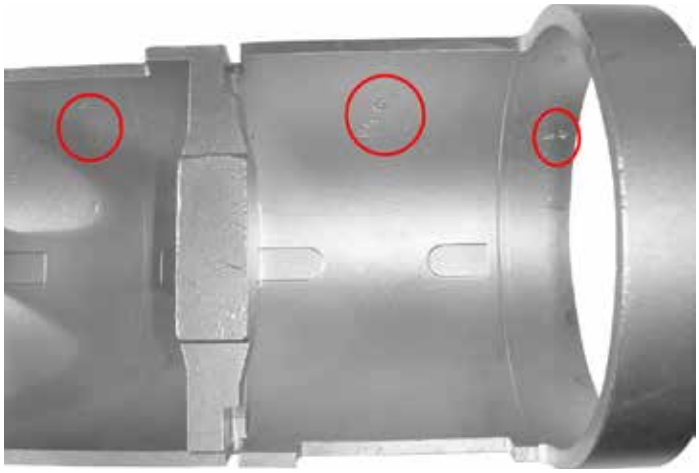
Aliases
Misrun

Method for defect determination
Visual Inspection

Area	Possible Cause	Potential Correction
Shell	Low mold permeability	Increase shell permability. Consider reducing shell thickness. Vent thin sections
Foundry	Low metal pouring temperature	Increase metal temperature, improve ladle preheating, speed time from tap to pour
Foundry	Low mold temperature	Speed time from oven to cast or insulate mold to prevent heat loss
Foundry	Interrupted pour.	Pour without interruption
Foundry	Lack of metal fluidity	Increase fluidity by reducing metal oxides or adjustment of the metal chemistry
Foundry	Poor gating system	Modify gating design to create more entry points for alloy

Non-Metallic Inclusion





Mechanism

Foreign material in the mold cavity which can originate either from the mold or from outside the mold. The shape of the defect aids in determination of the source

Description

Defect Type
Negative

Appearance
Generally a smooth sided irregular negative shape of indefinite size. Inclusions caused by ceramic material are usually more angular and may contain bits of embedded ceramic.

Size
Variable

Typical Location
Most obvious on external surface of casting where the “inclusion” prevented the alloy from filling the mold cavity to the shell surface.

Aliases
Dirt, Ash

Method for defect determination
Visual Inspection

Area	Possible Cause	Potential Correction
Wax	Junction between wax gate and sprue not completely sealed (undercuts). Ceramic fills the undercut during shelling and breaks off during dewax or pouring.	Improve gating technique to eliminate undercuts. Make sure wax joints (parts to sprue) are sooth and complete.
Wax	Filter breakage	
Wax	Ash in wax – as in wax typically floats in the molten alloy and is present on the top-side of castings	Test ash content of wax
Wax	Incomplete soluble removal	Confirm soluble leaching process and inspection is adequate
Wax	Filler settles out in areas that do not drain during dewaxing	Reconfigure gating design to improve wax removal. Add wax bleeder
Shell	Cracks in mold and ceramic bits get into mold cavity	See Finning

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Non-Metallic Inclusion

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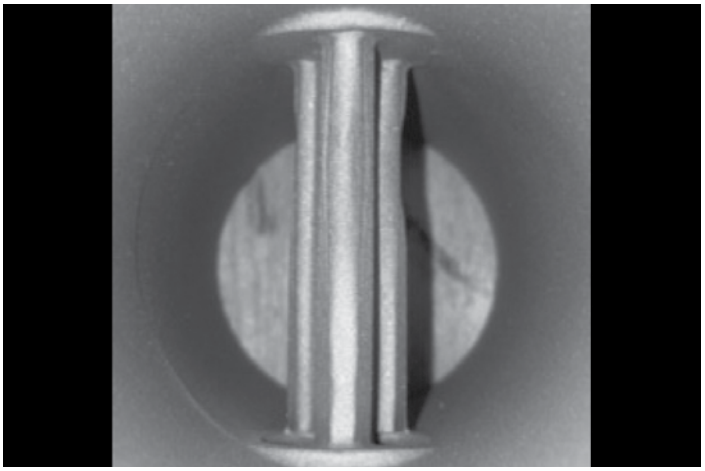
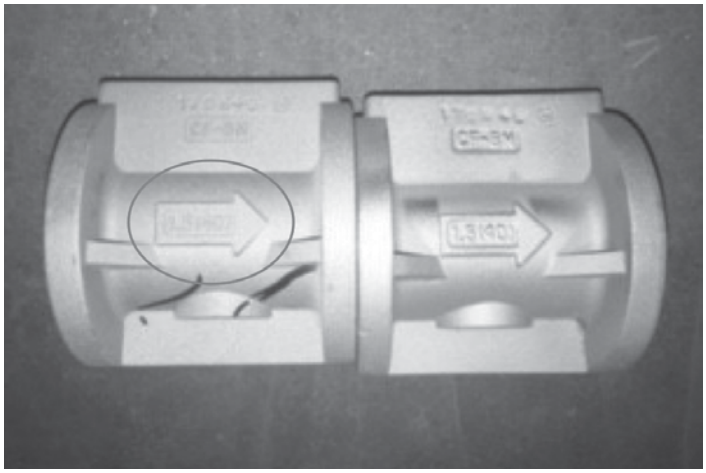
Area	Cause	Potential Correction
Shell	Poor mold patching technique – patch enters mold	Improve patch technique
Shell	Poor adhesion of shell layers to one another	See Spall
Shell	Ceramic debris entering mold after dewaxing (poor housekeeping)	Cover the pour cup after dewaxing (allow moisture from the mold to escape). Store the mold cup down. Wipe rim of pour cup before turning up-right
Shell	Ceramic breaking loose inside the mold during dewaxing	Vacuum or wash out mold after dewaxing
Shell	Slurry floods pour cup during shell building	Cover pour cup, immediately rinse slurry out. Remove all dried ceramic prior to dewaxing. Coat the inside of the pour cup with wax prior to shelling to aid in slurry removal from cup during dewax.
Shell	Ceramic material from jagged lip/edges on in house shell built pouring cups is broken off during handling, burnout or casting	Use a preformed ceramic pour cup or assure in house shelled cup is uniform and robust on top edge

Overblast





Mechanism

The blasting media used in mechanical cleaning equipment is typically harder than the casting. The surface of the casting can be deformed or eroded by extended blasting time or excessive blasting energy.

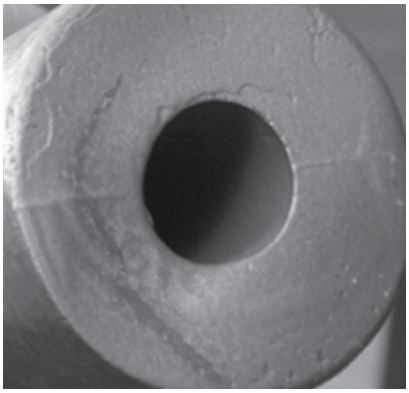
Description

Defect Type
Negative

Appearance
Small negatives possibly with accompanying burrs. Textured surface. May have rolled edges. Eroded features

Typical Location
Surfaces exposed to shot or sand blast media

Aliases
Blasting damage



Area	Possible Cause	Potential Correction
Other	The casting are too hot during blasting	Allow parts to cool prior to blasting
Other	Castings are stopped in front of the blasting nozzle or wheel	Insure the parts are constantly moving during the blasting cycle. Check the mill or spinners to confirm movement during the blast cycle
Other	Blast time is too long	Reduce blast time
Other	Blast media is too large	Reduce blast media size
Other	Blast media is too hard	Use softer blast media

Oxide

Mechanism

During casting a refractory oxide skin is formed in the melt through the exposure of reactive elements to oxygen. Certain elements are more reactive than others and will preferentially oxidize. The metallic oxide that is formed can be aggravated with turbulent filling.

Description

Defect Type
Negative

Appearance
Metallic oxides are thin black sub-surface streamers forming an irregular pattern or agglomeration on the surface of the casting.

Special Circumstances
More commonly encountered with alloys containing highly reactive elements (Ti, Al, Zr, Cr, etc.)

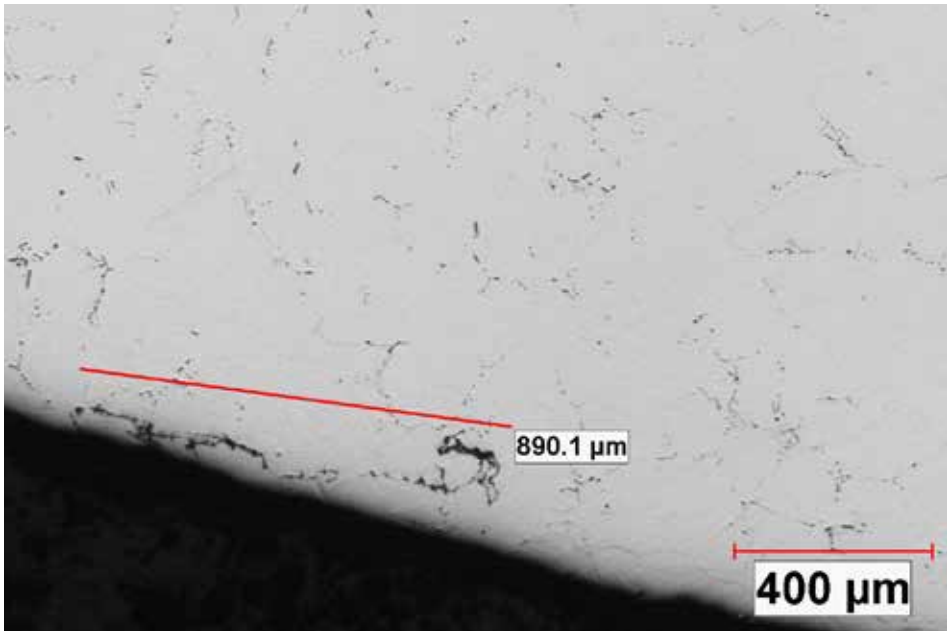
Size
Varies

Typical Location
Surface and subsurface

Similar to
Rat-tailing, Cold shut, Slag

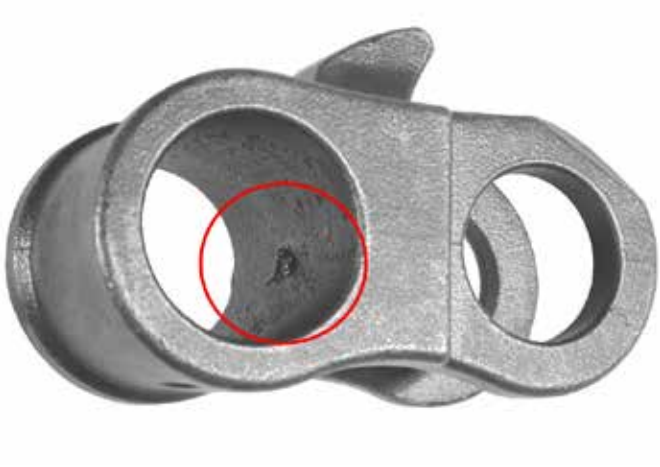
Aliases
Oxide Folds, Dross, Slag, Oxide Film

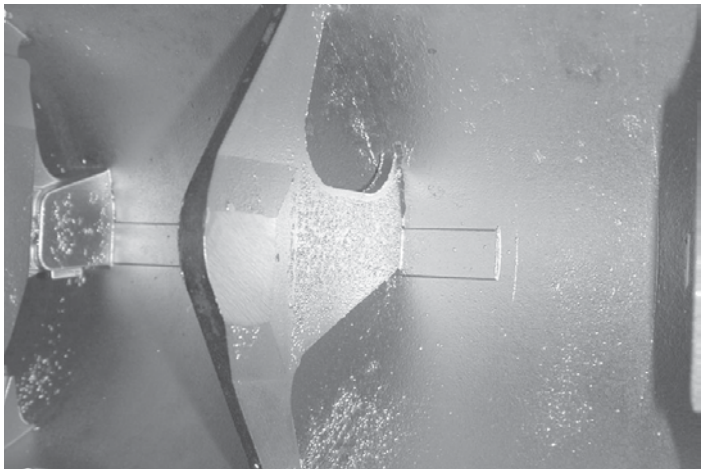
Method for defect determination
Metallic oxide indications tend to be thin, irregular, randomly placed or located, strings of materials containing oxygen and reactive elements. Metallic oxide indications can be determined by visual or EDS inspection.



Area	Possible Cause	Potential Correction
Foundry	Impure melting stock	Use oxide-free melting stock or filters
Foundry	Oxidation of reactive elements	Prevent oxidation of the melt through the use of vacuum or protective atmosphere
Foundry	Improper deoxidation practice	Allow time for deoxidation adds to be effective, agitate melt and de-slag for improved deoxidation
Foundry	Turbulence	Reduced filling speed

Penetration





Mechanism

Metal penetrates into the primary layer during casting. Pinholes or air pockets in the primary layer fill with metal during casting

OR

Stucco penetrates the primary surface and traps an air pocket against the wax

Description

Defect Type
Positive

Appearance
Small discrete positives which appear like grains of sand. When severe, the positives are closely clustered and the surface feels like sandpaper

Typical Location
Near gates, heavy sections or slow to cool sections of the casting

Aliases
Burn-in, burn on, pimpling, stucco penetration, rough surface

Method for defect determination
Visual inspection

Area	Possible Cause	Potential Correction
Shell	Stucco particles too large	Change shell code, use finer stucco on the first few shell layers
Shell	Incomplete slurry mixing	Insure the slurry is completely mixed before using in production
Shell	Foaming in slurry	Insure air is not being sucked into the slurry by the mixer. Conduct antifoam test and adjust if necessary
Shell	Primary slurry instability (micro-gelling) refractory solids)	Conduct gel test on binder solution. Replace slurry if bad
Shell	Prime slurry layer too thin	Increase slurry viscosity or reduce slurry drain time. Modify drain orientation. Double dip the mold in the slurry. Increase the pre-wet drain time or orientation
Shell	Reaction with primary coat contaminants	Ensure rusting or corrosion of the mixing equipment is not occurring. Remove iron contamination with magnets

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Penetration

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Area	Cause	Potential Correction
Shell	Drain time too long before stucco application	Optimize drain time. Train operators or adjust robot program
Shell	Rainfall sander too high above pattern	Raise pattern in relation to sand fall
Shell	Non-uniform sand delivery from rain rainfall equipment	Maintain or adjust equipment
Shell	Improper air flow in fluid bed	Reduce air flow as needed, keep bed clean. Maintain sufficient flow to avoid having to force patterns into bed
Foundry	High ferrostatic pressure	Reduce the height of the mold. Reduce the vacuum level. Reduce the spinning speed (centrifugal casting)
Foundry	Casting cooling rate too slow	Speed up casting cooling, insure cast molds are not too close together. If penetration localized to hot spots, improve radiant heat loss by length-ening gates or increasing the spacing between adjacent parts
Foundry	Oxidized metal	Improve melting and casting process to prevent oxidation of the melt
Foundry	Metal temperature too hot	Reduce metal temperature

Pinholes

Mechanism

Gases are absorbed in metal during melting. If the gas level in the melt exceeds the solid state solubility limit, bubbles are formed during solidification. The gases most responsible for this defect are hydrogen and nitrogen.

Alternate Mechanism
Chemically combined water in the mold is released by the increase in mold temperature during casting.

Description

Defect Type
Negative

Appearance
1/8” or less

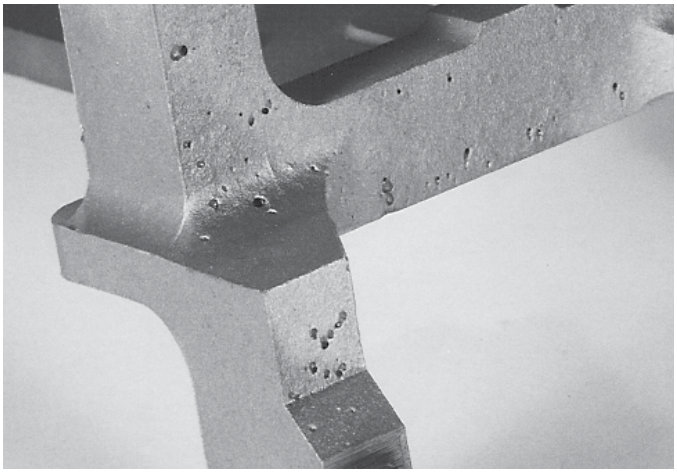
Size
1/8” or less

Typical Location
Dispersed throughout the casting but may be more severe in areas that are last to freeze

Similar to
Gas, Slag, Incomplete Burn-out

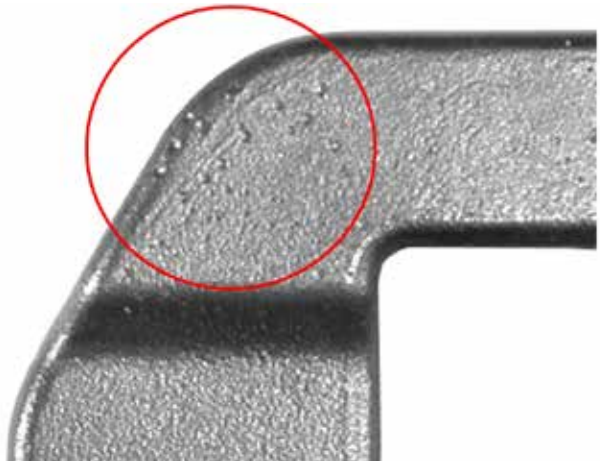
Aliases
Metallurgical gas

Method for defect determination
Pinhole defects are typically smaller with a higher frequency than gas, slag or incomplete burn-out. This defect is more common in plain carbon and low alloy steels than in higher alloy steels.



Area	Possible Cause	Potential Correction
Shell	Chemically combined water in the mold released during casting	Dry the molds completely after autoclave dewaxing. Increase the mold preheat temperature.
Foundry	High nitrogen, oxygen or hydrogen level in the melt	Use more virgin metal or purchase metal with lower gas content
Foundry	Dirty, wet or rusty metal	Metal should be clean, dry and free from rust and oils
Foundry	Wet ladles or pouring spouts	Insure complete heating and dry out of furnace pour spouts and ladles
Foundry	Incomplete degassing	Confirm degassing additions are correct
Foundry	High nitrogen, oxygen or hydrogen level absorption in the melt	Reduce the casting temperature or time the metal is molten. Use a protective or inert atmosphere around melt

Pitting



Mechanism

Oxygen reacts with chrome in the metal immediately after casting

Description

Defect Type
Negative

Appearance
A multiplicity of dark colored shallow depressions covering a large portion of the casting

Special Circumstances
Can only occur in high chrome alloys such as 400 series and PH stainless steels

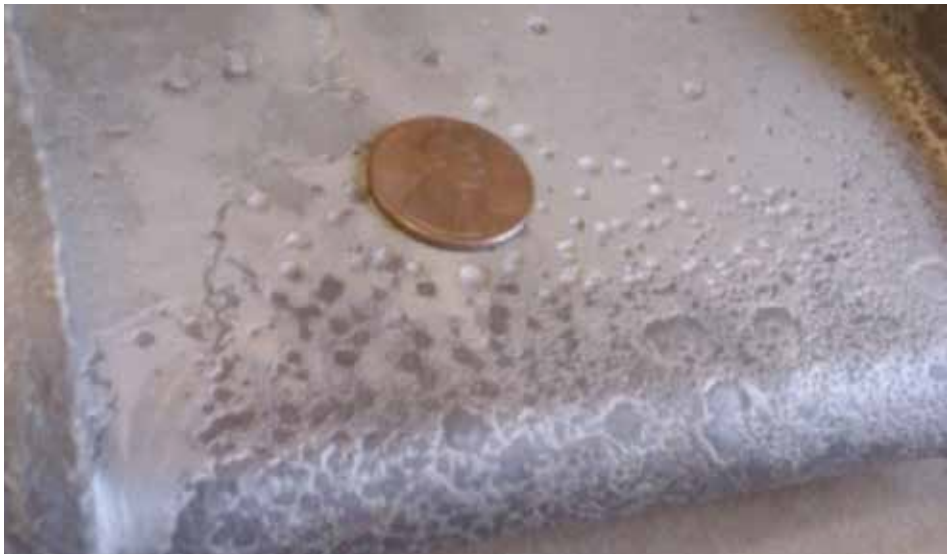
Typical Location
Thick, slow to cool sections

Similar to
Gas, Incomplete Burn-out, Slag

Aliases
Chrome Oxide Pitting, Fusion Spot, Measles

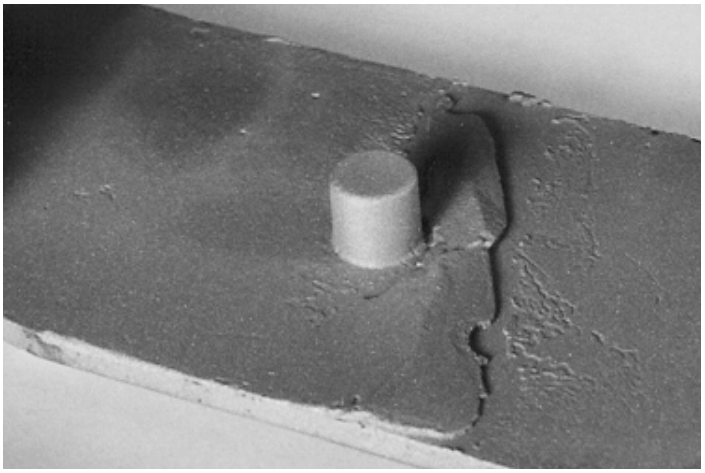
Method for defect determination
Alloy, number of defect sites, depth of defect

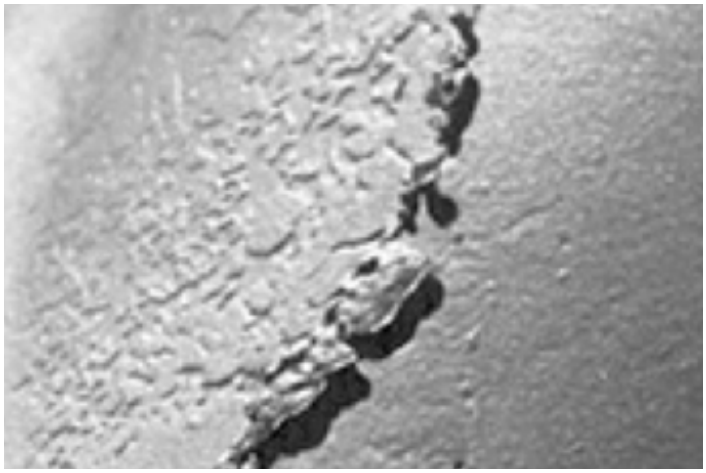
Area	Possible Cause	Potential Correction
Foundry	Surface oxidation of high chrome-iron alloys	Ensure reducing or inert conditions immediately after casting. Cover the molds after casting. Use carbonaceous materials in or around the mold. Cool in vacuum or protective or inert atmosphere
Foundry	Lack of carbona-ceous material in mold	Reduce mold burnout time or add additional carbon layers during shell building
Foundry	Casting cooling rate too slow	Increase casting cooling rate



Prime Coat Lift

An Investment Casting Institute Publication





Mechanism

During shell building, the primary coat cracks and lifts off the pattern. Subsequent slurry layers penetrate and fill the gap between the pattern and the primary coat. This defect is a close cousin to buckle

Description

Defect Type
Positive

Appearance
Island of surplus metal often associated with flash at the casting edge. The edge of the defect has the appearance of a coastline

Typical Location
Sharp corners adjacent to flat or featureless surfaces

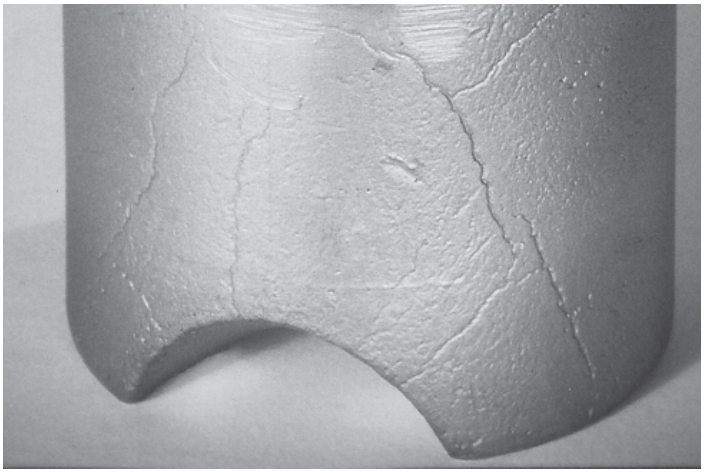
Similar to
Buckle

Aliases
Primary coat buckle, investment penetration

Method for defect determination
With prime coat lift, the shell also fractures, allowing the backup layers to fill the gap between the primary layer and the wax pattern. When a shell buckles, it only separates from the pattern.

Area	Possible Cause	Potential Correction
Wax	Wax pattern temperature not stable	Ensure the wax pattern has stabilized in temperature before applying shell layers
Shell	Poor adhesion of the prime coat to the wax pattern	Increase the etch strength or etch time. Reduce the time from etch to 1st layer application
Shell	Large temperature drop when applying 2nd layer	Increase the room humidity
Shell	Large temperature variation during prime coat drying	Maintain +/- 3 F in the dipping and drying area
Shell	Drying too long	Shorten the dry time
Shell	Drying too fast (large pattern shrinkage)	Increase the room humidity or reduce airflow
Shell	Primary coat binder is gelled	Test the primary coat binder to determine if it is gelled
Shell	Uneven primary coating thickness giving rise to variable rates of drying	Modify the draining technique to produce a more uniform slurry coverage
Shell	Slurry dry out on sharp edges	Shorten the draining time, increase the humidity in the shell dipping area
Shell	Poor adhesion and elasticity properties of the primary slurry	Green strength additives in the primary slurry becoming unstable or ineffective

Rat-tailing



Mechanism

This defect is a marriage of pitting and finning defects. Rat-tailing is the selective oxidation of the metal surface through cracks or micro-cracks in the shell. Most of the cracks are large enough to be filled with metal during pouring and will produce positive metal fins. Very fine micro-cracks are too small to allow metal to enter, but will allow air (oxygen) to reach the hot casting surface.

Description

Defect Type
Negative with the possibility of positive finning

Appearance
Shallow rounded threadlike fissures typically in a radial pattern

Aliases
Mud cracks, drying cracks, oxidation crazing, rivering

Method for defect determination
Thin, negative defect typically found in high chrome alloys

Area	Possible Cause	Potential Correction
Other (Set-up)	Lack of stress raisers on the cast surfaces or in the primary coat refractories	Break-up large flat surfaces on the casting with “hatching” or small ribs which can subsequently be ground off
Shell	Large temperature variation during prime coat drying	Maintain +/- 3F in the drying area
Shell	Drying too fast (large pattern shrinkage)	Casting cooling rate too slow. Increase dipping and drying room humidity, reduce air flow
Shell	Mismatch in expansion coefficient between prime and backup coats	Use slurry and stucco refractories with similar thermal expansion rates
Shell	Drying too long	Reduce dry time. cooling rate too slow
Shell	Low prime coat strength	Check binder healthy/stability through pH, conductivity and/or gel test
Shell	Low prime coat strength	Increase refractory solids

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Rat-tailing

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Area	Cause	Potential Correction
Shell	Poor adhesion and elasticity properties of the primary slurry	Green strength additives in the primary slurry becoming unstable or ineffective
Shell	Uneven shell build on prime coat(s)	Evaluate dipping/draining sequence to ensure uniform draining and/or shell build
Shell	Permeability of shell is too high	Compare permeability of shell against previous data. If changed, evaluate potential causes for increase
Foundry	Oxygen level too high during casting cooling	Ensure reducing or inert conditions immediately after casting. Cover the molds after casting. Use carbonaceous materials in or around the mold. Cool in vacuum or protective atmosphere
Foundry	Oxygen level too high during casting. Casting cooling rate too slow	Casting speed cooling rate too slow
Foundry	High shell temperature and excessive time in oven	Explore potential ways to reduce shell pre-heat temperature or time

Shot Defect

Mechanism

During casting, droplets of metal detach or are separated from the pouring stream by excessive turbulence, mold design, or metal pouring height. The metal droplet becomes either cooler in temperature or coated with a tenacious oxide film and retains this identity as part of the cast metal.

Description

Defect Type
Negative

Appearance
These are closely related to oxide fold defects but are typically circular in form rather than linear

Size
Can be small up to an inch or more in diameter

Typical Location
Generally located on the surface of the casting

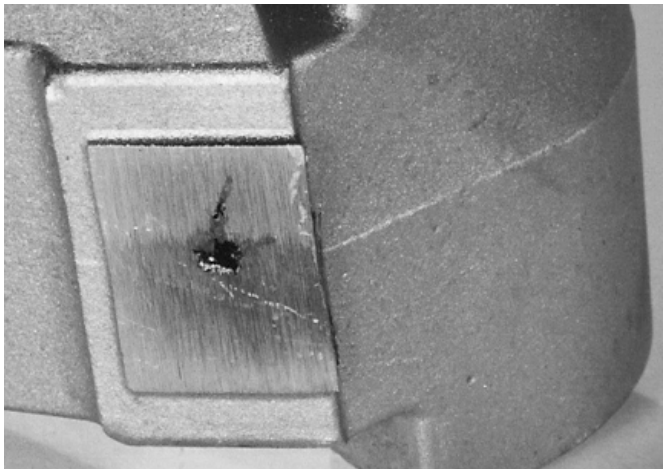
Similar to
Wax flow lines (See Atlas of Wax Pattern Defects)

Aliases
Oxidized droplet

Method for defect determination
Visual or Fluorescent Penetrant Inspection

Area	Possible Cause	Potential Correction
Wax	Cold wax at nozzle tip	Wax cold shot can occur in the wax pattern and be duplicated through the shelling process, thereby resulting in a similar-looking metal defect. (Ensure nozzle tip temperature is adequate to keep wax from solidifying).
Other (Mold design)	Bad mold design	Mold design should promote non-turbulent metal flow
Foundry	Bad pouring practice	Avoid metal splashing during pouring
Foundry	Bad pouring practice	Reducing the distance between the crucible and the mold to be poured to minimum, thereby reducing the chance for splashing
Foundry	Pouring practice	Employ use of a reticulated foam filter to achieve a laminar flow
Foundry	Pouring practice	Formation of a well in the mold to allow the metal to collect and then flow into the mold parts

Shrink - Gate



Mechanism

The molten alloy shrinks as it solidifies. Inadequate feed metal from the gating system is available to prevent a cavity from forming.

Description

Defect Type
Negative

Appearance
Internal irregular cavity exhibiting an open or porous coarsely crystalline or dendritic structure usually exposed upon removal of the gate. This defect is frequently discovered by caustic salt bleed out from the cavity

Typical Location
Center of gates

Similar to
Shrink - Surface, Shrink - Internal

Method for defect determination
Visual inspection,
Penetrant Inspection

Area	Possible Cause	Potential Correction
Other (Gating design)	Gates are too small or too long	Increase height of mold to increase ferrostatic pressure or the gate modulus, consider tapering the gate
Other (Casting design)	Low metal pressure	Insulate, hot top or use exothermic material to prevent the pour cup from freezing too early
Foundry	Runner system freezing too early	Use selective insulation to promote progressive solidification
Foundry	Gates are too small or too long	Increase height of mold to increase ferrostatic pressure or the gate modulus, consider tapering the gate

Shrink - Internal

Mechanism

Molten alloys shrink as they solidify. As solidification progresses and the solid to liquid fraction increases, it becomes more difficult for liquid feed metal to reach the solidification front. Shrinkage occurs between dendritic arms. In larger defects, inadequate feed metal is provided to isolated hot spots in the casting.

Description

Defect Type
Negative

Appearance
Internal irregular cavities ranging from small dispersed or linear type cavities up to large cavities

Special Circumstances
The occurrence and severity of this defect may be alloy dependent. Alloys with longer (larger) freezing ranges are more prone to this defect.

Size
Shrinkage cavities can range in size from very small (requiring magnification) to very large

Typical Location
Casting centerline between gates or in isolated heavy sections. Areas with sharp internal corners

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Area	Possible Cause	Potential Correction
Other (Mold design)	Inadequate or incorrect feeding	Ensure adequate feeding of the area concerned to promote progressive solidification
Other (Mold design)	Incorrect solidification rate	Modify the casting design to promote progressive solidification
Other (Mold design)	Vacuum in blind riser	Ensure the v-notch in the riser prevents a vacuum from forming
Other (Mold design)	Blind riser too small	Ensure the riser has adequate metal volume
Other (Mold design)	Low ferrostatic head pressure	Increase the height of the mold. Use centrifugal force to increase head pressure
Other (Mold design)	Incorrect solidification rate	Examine the molding technique. Modify the casting design to promote progressive solidification.
Foundry	Incorrect casting conditions	Establish the correct casting conditions

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Shrink - Internal

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Similar to
Shrink - Gate, Shrink - Surface

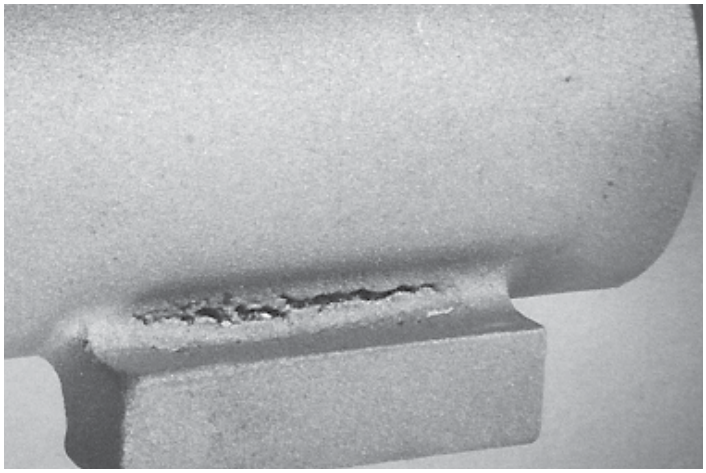
Aliases
Dendritic shrink, micro-shrink

Method for defect determination
Because this is a subsurface defect, if may not be discovered without x-ray examination, machining or sectioning through the casting.

continued from previous page

Area	Cause	Potential Correction
Foundry	Incorrect solidification rate	Use insulation on specific areas of the mold to increase thermal gradient
Foundry	Low metal temperature	Increasing the metal temperature can improve the feeding distance
Foundry	Low mold temperature	Increasing the mold temperature can improve feeding distance
Foundry	Vacuum created in the feeding system during solidification	Ensure the metal in the head (pour cup) remains liquid longer than the casting. Insulate or use exothermic material on the pour cup and risers
Foundry	Dissolved gas level too high	Use a heat makeup and melting practice that produce low dissolved gases
Other (Casting Processing)	Inadequate or incorrect feeding	Use hot isostatic pressing (HIP) to close up the defects. Cap weld all surface connected shrinkage prior to HIP.

Shrink - Surface



Mechanism

The molten alloy shrinks as it solidifies. Sharp inside corners thermally saturate the shell and cool slower than the surrounding area. Unfavorable thermal geometry resulting in an isolated liquid metal heat center. The shrinkage of the internal section, cut off from supplies of further liquid feed metal, causes atmospheric pressure to collapse the adjacent skin where the metal is still sufficiently hot and weak to do so.

Description

Defect Type
Negative

Appearance
Surface depression or irregular cavities exhibiting an open or porous or coarsely crystalline structure sometimes exhibiting a dendritic appearance. These defects are frequently discovered by caustic salt bleeding out of the cavity after the leaching.

Typical Location
Fillets, sharp intersections. or slow and are commonly found at corners of castings near the ingate

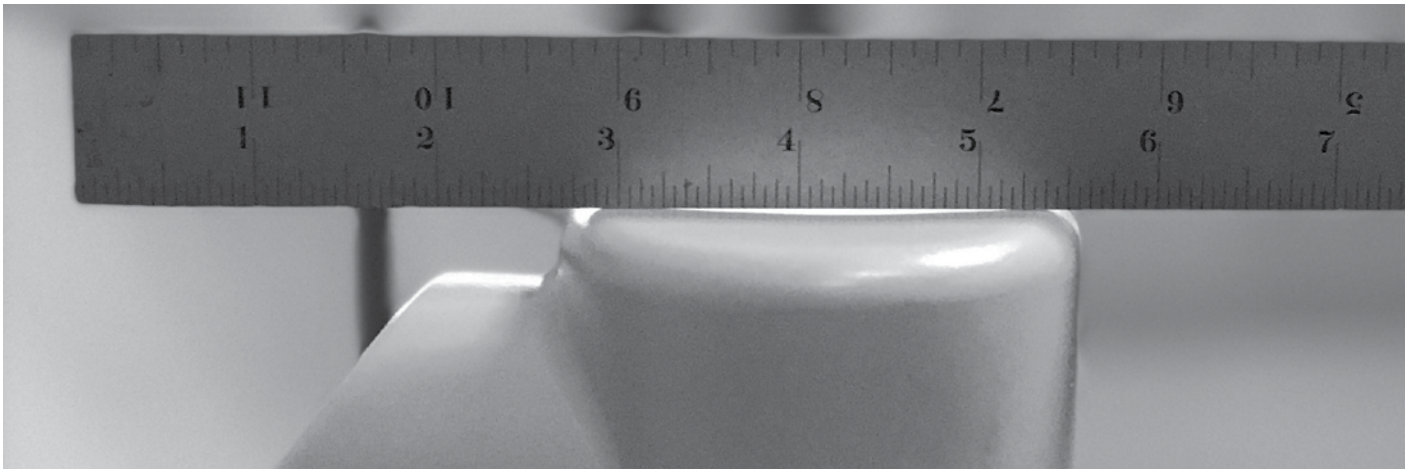
Similar to
Shrink - Gate, Shrink - Internal

Aliases
Hot spot porosity

Method for defect determination
Visual and Penetrant inspection

Area	Possible Cause	Potential Correction
Wax	Fillet too small	Increase fillet size
Wax	Inadequate feeding. Castings too close together – localized mold hot spots	Ensure adequate feeding. Improve pattern spacing and avoid refractory build-up in completing molds.
Foundry	Metal pouring temperature too hot	Consider reducing temperature
Foundry	Mold temperature too hot	Consider reducing temperature
Other (Metal/ Mold design	Differences in radiant cooling.	Review the assembled mold. Is the defect related to a specific position on the mold?
Other (Casting design)	Fillet too small	Increase fillet size
Other (Mold design)	Inadequate feeding. Castings too close together – localized mold hot spots	Ensure adequate feeding. Improve pattern spacing and avoid refractory build-up in completing molds.

Sink



Mechanism

Heavy section of wax pattern shrinks as it cools. The vacuum created during cooling causes the surface to cavitate or dish inward.

Description

Defect Type
Negative

Appearance
Smooth, dished surface depression

Size
varies

Typical Location
Heavy sections or thick flat surfaces

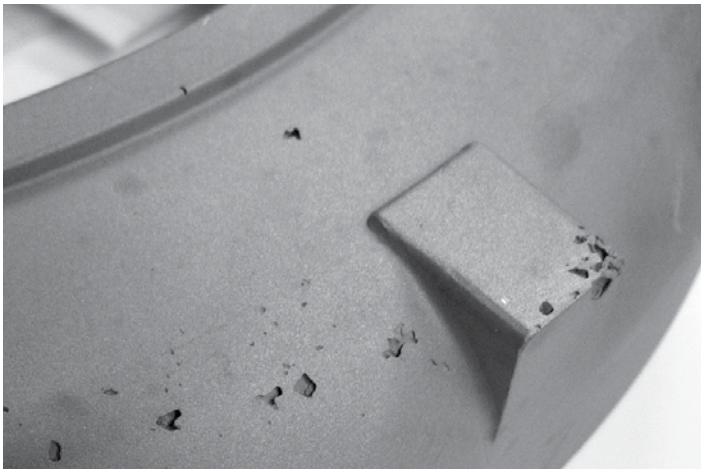
Similar to
Wax Shrink (See Atlas of Wax Pattern Defects)

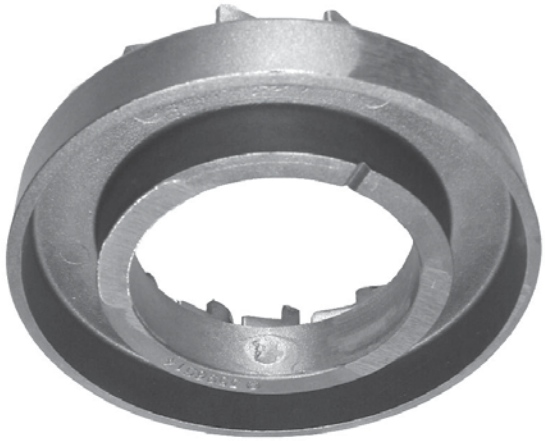
Aliases
Cavitation

Method for defect determination
Visual inspection, overlay of straight edge or customary dimensional inspection tools

Area	Possible Cause	Potential Correction
Other (Wax Tool Design)	Feed runner freezing prematurely	Increase size or add runner to affected section
Wax	Incorrect wax injection parameters	Reduce wax temperature, increase injection time, increase injection pressure
Wax	Missing wax chill	Create wax chill to reduce the volume of injected wax in the area of sink/cavitation
Wax	Hot wax chill	Allow time for the wax chill to cool to room temperature before inserting in the wax injection die

Slag





Mechanism

During melting or casting, slag is produced as a function of time, temperature and availability of oxygen. This slag is mixed with the metal during pouring and, being less dense than the metal, floats to the top surface of the casting.

Description

Defect Type
Negative

Appearance
A series of smooth-walled symmetrical surface cavities with or without traces of dark glassy included material

Typical Location
Top surface of the casting as oriented at casting

Similar to
Gas, Pinholes, Incomplete Burn-out

Method for defect determination
It is difficult to visually distinguish between slag and gas defects. The defect shapes are similar as is the location. Inspection of the defect under magnification may reveal residual slag.

Area	Possible Cause	Potential Correction
Shell	Metal / mold reaction	Cast at the lowest possible mold and metal temperature. Increase the refractoriness of the primary coat
Foundry	Crucible / metal reaction	Employ correct crucible and melting practice
Foundry	Oxidation of furnace lining or ladle	Change to more refractory material
Foundry	Poor or improper deslagging practice	Ensure adequate slag removal at lowest possible temperature. Allow time for slag in melt to float out. Remove slag. Use slag coagulants if necessary to improve removal.
Foundry	Excessive superheat temperature and or holding times	Minimize the time the metal is at temperature
Foundry	Oxidation of metal during melting	Consider protecting the melt using inert gas
Foundry	Silicates formed during deoxidation	Modify the deoxidation practice

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Slag

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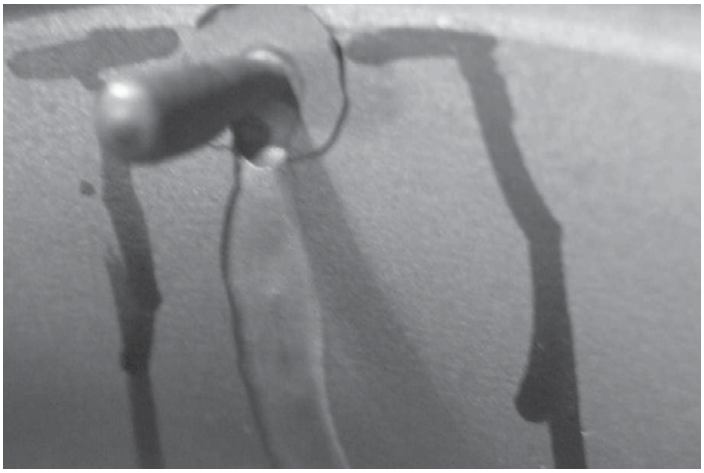
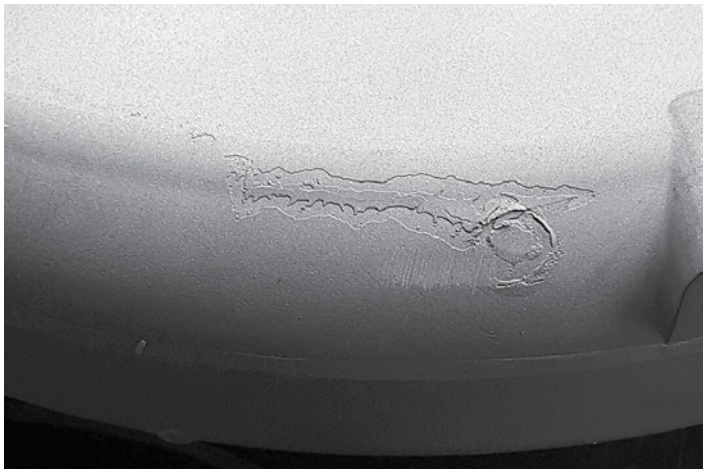
Area	Cause	Potential Correction
Foundry	Slag from the ladle entering the mold	Use ceramic or cloth filter
Foundry	Slag from ladle entering the mold	Consider using a bottom pour (teapot) ladle
Foundry	Turbulent pouring conditions - metal poured from great height above molds	Minimize the distance from the furnace / ladle to the mold

Slurry Leakage





Mechanism

Liquid ceramic slurry enters the mold and dries creating a positive in the mold that is represented as a negative in the casting

Description

Defect Type
Negative

Appearance
Shallow, irregular depression in casting surface

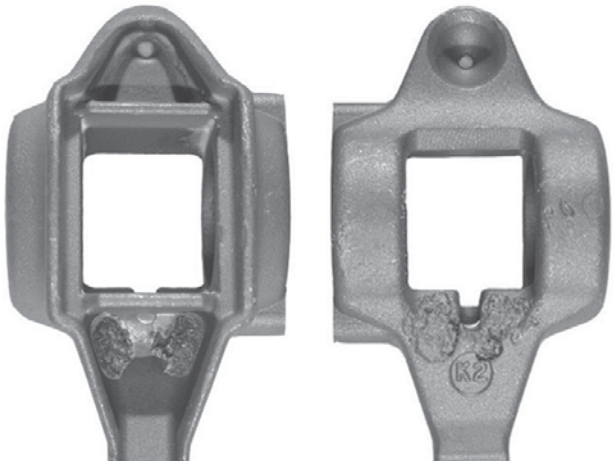
Size
varies

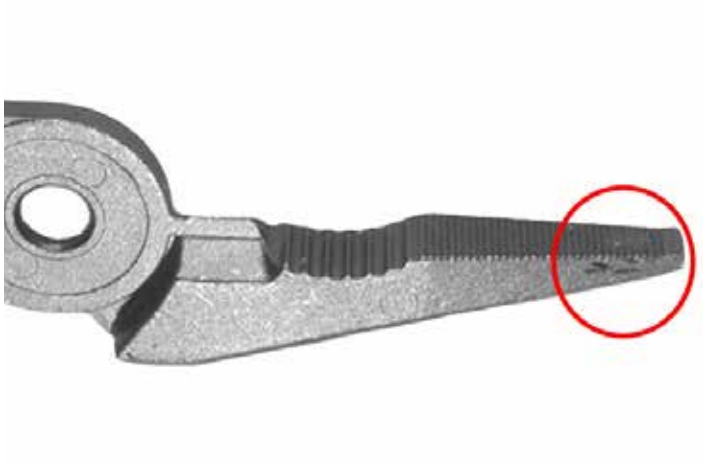
Typical Location
Near wax vent or in mold crack

Method for defect determination
Visual inspection

Area	Possible Cause	Potential Correction
Shell	Damage to coating creates separation from wax passage for slurry entry	Awareness/Handling
Other (Mold Preparation)	Inadvertent spill	Awareness/Cleanliness

Spall





Mechanism

The layer to layer bond in the shell construction is not strong enough and the ceramic fractures off the mold surface during dewaxing, mold preheating or casting and falls into the mold cavity

Description

Defect Type
Positive (with corresponding negative)

Appearance
Sharp or irregular positive defect normally accompanied by a negative defect (inclusion) from the ceramic that has “spalled” off and appears somewhere else on the casting.

Typical Location
Detailed areas such as depressed lettering, score lines, teeth, tight slots, fillets or sharp corners

Similar to
Penetration (positive), Non-Metallic Inclusions (negative)

Aliases
Spalling, prime coat spall, pre-coat spall, undercuts

Method for defect determination
Visual Inspection

Area	Possible Cause	Potential Correction
Shell	Excessive 1st layer slurry that results in weak inter layer shell construction	Fully drain slurry coats
Shell	Incomplete 1st layer dry that results in weak inter layer shell construction	Extend prime slurry dry time
Shell	Excessive pre-wet that results in weak inter layer shell construction	Fully drain pre-wet to matte finish
Shell	Prime coat stucco too fine that results in weak inter layer shell construction	Skim fines/dust from the fluid bed or screen out, use coarser stucco
Shell	Low primary slurry binder level	Check SiO2 level of primary slurry
Shell	Prime slurry binder gelling	Conduct gel test on primary slurry binder

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Spall

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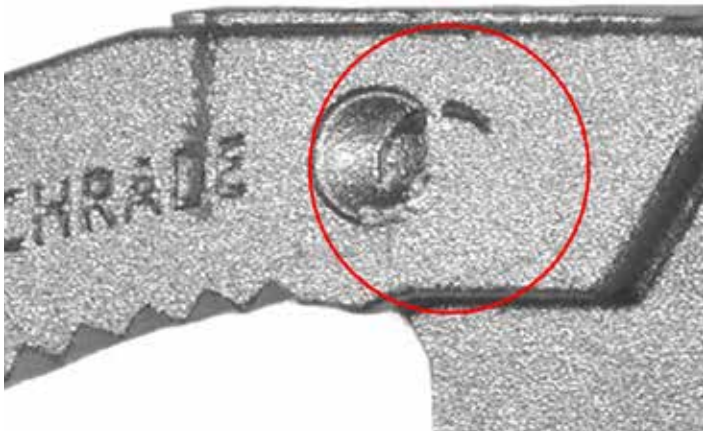
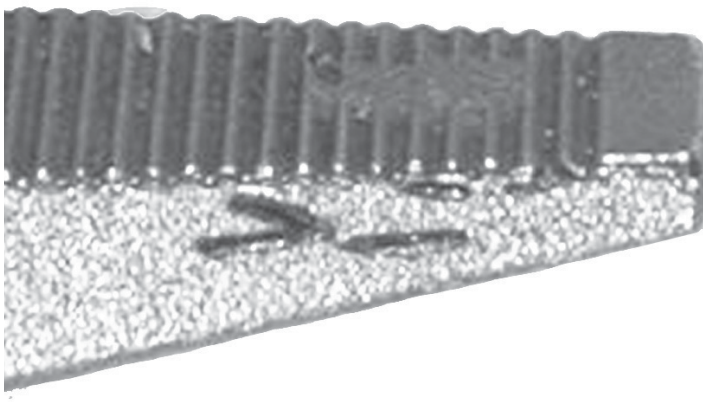
Area	Cause	Potential Correction
Shell	Poor stucco adhesion	Insure the slurry is not drying before stucco, eliminate stucco rub off, blow off loose stucco
Shell	Prime coat slurry too thick	Reduce prime coat viscosity
Shell	Etch too strong	Reduce etch time, etch strength or increase time from etch to 1st layer application
Shell	Thermal expansion mismatch	Use refractories that have similar thermal expansion characteristics





Stuck Shot

Mechanism

Shot wedged into lettering or detailed areas during shot blasting operation

Description

Defect Type
Positive

Appearance
Smooth - round, oval, or hemispherical

Special Circumstances
Can only occur in areas of the casting that shot can get wedged into

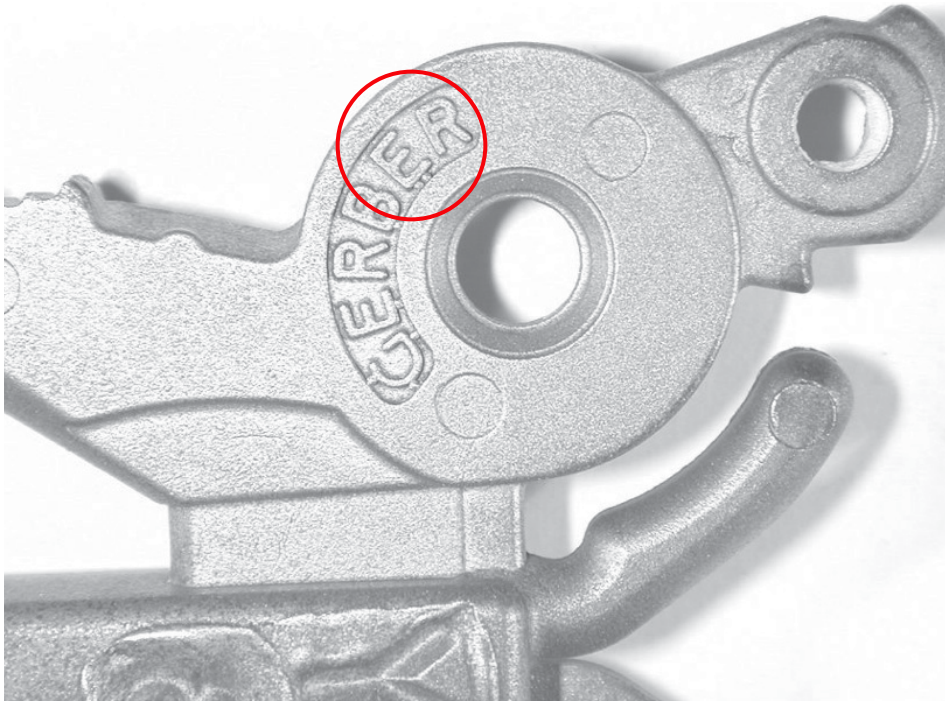
Size
1/8” or less

Typical Location
Highly detailed areas such as depressed lettering or score lines

Similar to
Wax bubbles (See Atlas of Wax Pattern Defects), Bubbles

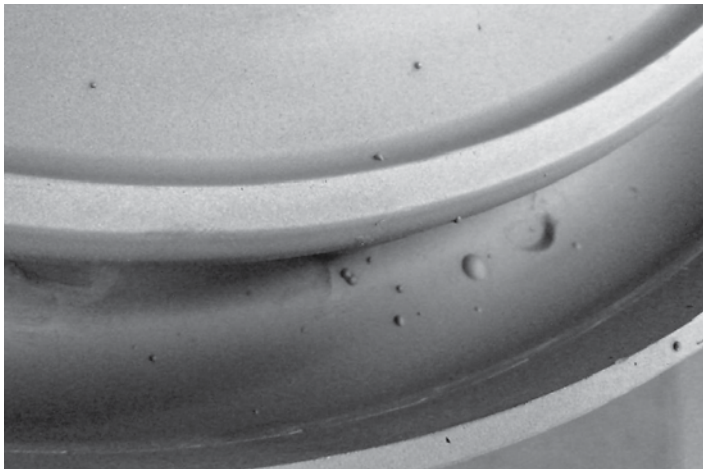
Aliases
Positive metal

Method for defect determination
Stuck shot can be pried out. Can also section, mount and polish through defect. Stuck shot will not be attached to the casting – only wedged in place



Area	Possible Cause	Potential Correction
Other (Shot blast)	Shot is the wrong size for the part	Change the shot size

Wax Drip



Mechanism

Molten Wax or sticky wax drips onto the pattern during gating assembly process

Description

Defect Type
Positive

Appearance
Smooth. Spherical or oval shaped sometimes accompanied with a tail.

Typical Location
Exposed surface during gating

Aliases
Wax Splatter

Method for defect determination
visual

Area	Possible Cause	Potential Correction
Wax	Wax melting iron / torch too hot	Reduce temperature
Wax	Sticky wax too hot	Reduce to correct temperature
Wax	Poor gating technique	Use a shield (aluminum foil) to prevent drips from getting on the pattern

List of Defects

Aliases

Bubbles
BBs
Air bubble

Bulge
Bulging
Bulging cracking
Bulging overheating
Shell bulge

Cold Shut
Cold shot
Short fill

Delamination
Scabbing
Reverse buckle

Etch Spotting
Fisheyes

Excess Metal
Metal breakthrough
Metal penetration
Core collapse

Finning
Flash
Shell crack
Mold crack

Gas
Entrapped air
Porosity

Handling Damage
Knockout Damage

Hot Tear
Shrinkage crack

Leaker
Runout
Short pour

Non-metallic Inclusions
Dirt
Ash

Non Fill
Misrun
Cold shut

Overblast
Blasting Damage

Oxides
Misrun
Cold shut
Oxide folds
Dross
Oxide film

Penetration
Burn-in
Burn-on
Pimpling
Stucco penetration
Rough surface

Pinholes
Metallurgical gas

Pitting
Chrome oxide pitting
Fusion spot
Measles

Prime Coat Lift
Primary coat buckle
Investment penetration

Rat Tailing
Mud cracks
Drying cracks
Oxidation crazing
Rivering

Shot Defect
Oxidized droplet

Shrink – Internal
Micro-shrink
Dendritic shrink

Shrink – Surface
Hot spot porosity

Sink
Cavitation

Spall
Spalling
Prime coat spall
Pre-coat spall
Undercuts

Stuck Shot
Positive metal

Wax Drip
Wax Splatter

***** *See ICI Atlas of Wax Pattern Defects*

The Wax Atlas can be accessed at www.investmentcasting.org or ordered by contacting (201) 573-9770

Other ICI publications

Atlas of Wax Pattern Defects, REVISED 2ND Edition
A listing of probable cause effect relationships with the variables relating to the wax pattern area. Such problems as sink; cavitation; shrink; pattern crack; chill damage; air bubbles; flash; pattern distortion are examined. This atlas can be used as a new learning tool, a stimulating refresher for the more experienced caster, or as a tool for brain-storming a discovered defect. 2003, Investment Casting Institute.

Ceramics Testing Guidebook
Prepared by the Ceramics Committee of the Investment Casting Institute this book contains technical information on refractories and chemical materials used in investment casting, as well as testing procedures for refractory materials, colloidal silica binders, ethyl silicate binders and miscellaneous chemicals. Also includes testing procedures for solid mold materials, slurries and shells, ceramic cores and shapes. This and the ceramic video training series are a must for every investment casting operation! Revised 2005.

Finishing Operations
Finishing Operations covers robotic deburring and polishing, abrasive cut-off wheels, economics of friction sawing investment castings, rapid grinding gate removal abrasive sandblasting media, the basics of blast cleaning, gate and sprue removal with belts, final part finishing, air grinding tools, portable wheels and mounted points, carbide burs, and hot straightening of investment casting. 1989, Investment Casting Institute.

Fundamentals of SPC
Details principles of process and cost improvement, data collection, statistics and methodology while demonstrating data plotting and interpretation. Many case studies and examples. A top notch presentation by the Investment Casting Institute.

How to Avoid Shell Cracking: A Symposium
Based on an Investment Casting Institute training symposium, this book contains 13 papers from experts throughout the industry with practical information on how to avoid shell cracking. Papers cover the gamut: design, wax properties, raw materials, slurry control, environmental conditions in drying, autoclave, dewaxing, and handling. 1989, Investment Casting Institute.

Investment Casting 101 Booklet
Investment Casting 101 is a compact booklet providing a brief look at the basics of the investment casting process and how it works, an overview of the benefits of investment casting, why and when it makes sense, and dozens of pictures illustrating various applications. This is a great marketing tool priced low enough that investment casters can send it or give to all their potential customers.

Investment Casting Case Studies and Applications Published 2014 - Set of 20
The Investment Casting Case Studies and Applications supplement, which appeared in the August issue of INCAST, is now available as a marketing tool to Investment Casters. The 28-page, full-color booklet illustrates scores of investment casting applications in aerospace, industrial gas turbine, medical, automotive, military, sports/recreation and commercial/industrial markets. Many photos are accompanied by case studies which explain why investment casting was the preferred manufacturing process. The new publication clearly shows the flexibility and benefits of the investment casting process and since company names are not used, it is the process rather than the individual caster which is promoted.

Investment Casting Handbook
Put this resource in the hands of your potential customers! An excellent tool for designers, buyers and users of investment castings, as well as for employees in the investment casting foundry. Contains chapters on the following: 1). The Investment Casting Process; 2). How to Buy Investment Castings; 3). Dimensions, Tolerances, and Surface Texture; 4). Designs and Applications of Investment Casting; 5). Quality, Evaluation, Inspection and Control; 6). Alloy Selection. Plus numerous case studies, examples and dozens of full-color illustrations. 1997, Investment Casting Institute, 123 pp., illus.

Metal Standards and Specifications for Investment Castings
Metal Standards and Specifications for Investment Castings defines a typical level of metal quality by the industry as a service to purchasers of investment castings who do not cite detailed specifications. This includes a list of the most common investment casting alloys, chemistries and typical mechanical properties. A revision of the old standby Metal Quality Standards, the new book is intended as a handy reference guide not only for foundries, but also for end users.

For more information about ICI's other publications please visit: www.investmentcasting.org.