An Investment Casting Institute Publication

Atlas of Wax Pattern Defects

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In the process of wax pattern manufacturing, there can be a number of obstacles a producer may face in making high quality wax pattern consistently. There can be challenges associated with pattern dies, waxes, cores, equipment and/or process parameters that may result in defects causing unnecessary rework and scrap. It is recognized that if the wax pattern is of good quality, the producer has a proper start toward meeting the goal of a high quality and cost-effective casting.

This manual is provided to assist process engineers and wax injection personnel identify defects in wax patterns. It offers suggested and remedies to reduce or eliminate defects. Wax injection is a complex relationship between material and injection parameters. For further resources or classes to obtain a greater understanding please contact the ICI.

The manual is in an easy-to-use format. Photos provide a visual of the defect; text provides a list of probable causes and the suggested remedies. The most probable cause is listed first. The causes and remedies are categorized as “Equipment,” “Pattern Die,” “Wax,” and “Other.” The manual is divided into three sections.

Acknowledgments

The Investment Casting Institute wishes to thank all of the members of the Institute’s Publication and Wax Committees who provided information, photographs and valuable resources. This excellent support has made it possible to create this Atlas of Wax Pattern Defects, an educational tool that will be of great value to the industry now and in the future.

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Section 1
Defects in Patterns

The many defects described in the following pages are not typically difficult to identify and the pictures are valuable in supporting the decision. In the process of wax pattern manufacturing, there can be a number of obstacles a producer may face in making high quality wax pattern consistently. It should be understood that any investigation into pattern defects begins with a review of calibration and the many items contained in the Best Practices section.

The interplay between flow settings, injection pressure, and wax temperature are often difficult to understand as they are highly dependent on the runner and part cavity geometry. If suggestions for potential cure do not bring success it is always wise to contact your wax equipment manufacturer as well as the wax supplier. They will often have great insight and direct you toward elimination of the defect.

Defects

Air Bubbles

Mechanism

Air entrained in turbulent wax, compressed under the force of injection pressure, later expands to create a surface bulge.

Description

Defect Type
Positive

Appearance
Smooth bulging, often single but sometimes multiple sites

Size
Varies

Typical Location
Random

Method for defect determination
Visual Inspection with the assistance of tangential lighting

Area	Possible Cause	Potential Correction
Equipment	Excessive injection flow rate	Reduce wax flow rate. Note: Excessive flow rate causing turbulence can entrap air during injection of wax.
Equipment	Excessive acceleration rate Machines equipped with electronic injection control)	Reduce acceleration rate. If available, used "stepped flow" to reduce initial flow rate until cavity is partially filled.
Equipment	Incorrect nozzle temperature	Adjust nozzle temperature to match wax injection temperature.
Equipment	Improper wax conditioning	Condition wax according to manufacturer's instructions.
Equipment	High wax temperature	Reduce wax temperature.
Equipment	High clamping pressure	Reduce clamping pressure. High clamp pressure may shut off vents.
Equipment	Injection system seal or nozzle tip leakage	Replace defective seals. Tighten threaded connections.

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Air Bubbles
continued

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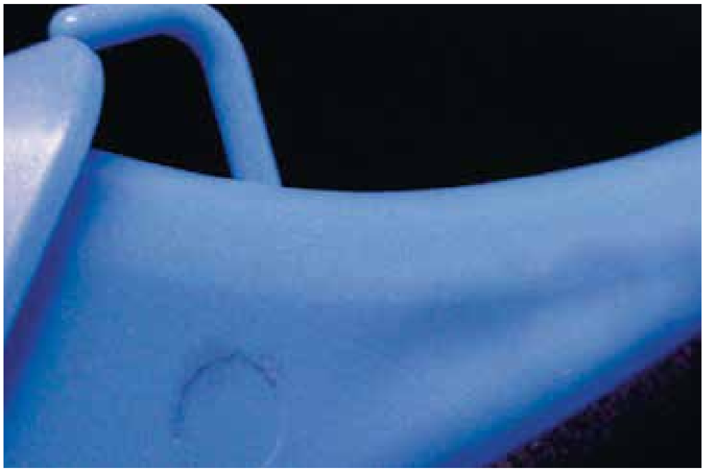
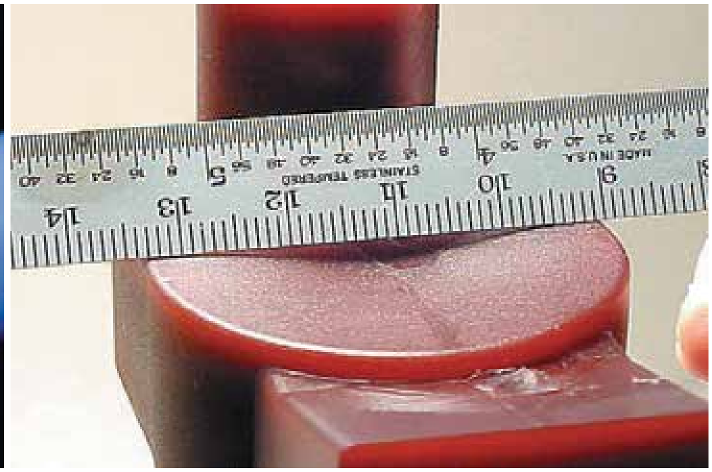
Area	Possible Cause	Potential Correction
Equipment	Equipment Injection chamber fill rate too fast	Reduce fill rate; consult equipment manufacturer.
Pattern Die	Improper design of vents	Add or relocate vent(s) in die cavity; ensure that existing vents are kept clean. See Best Practices Section.
Pattern Die	Improper size and/or location of wax injection sprue	Correct size and/or location of wax injection runner to reduce or eliminate turbulence.
Pattern Die	Die orientation to press	Turn die upside down.
Pattern Die	High die temperature	Decrease die temperature.
Wax	Defective solid wax billets	Ensure that billets are produced without air.
Wax	Damaged solid wax billets	Repair or replace damaged billets. Note: Billets that have rough surfaces or are damaged can entrain and trap air which can be transferred to wax patterns.
Other	Improper loading of liquid wax	Air can be entrapped by careless filling of the wax press with hot wax. Note: Melted wax should be poured into reservoir slowly, creating as little turbulence as possible. Proper wax conditioning techniques should be evaluated.
Other	Excessive mold release	Reduce use of mold release. Note: Excessive amounts of mold release on surface of mating die halves can act as a “gasket” and shutoff vents; clean die halves to remove excess mold release. (see best practices).

Cavitation





Mechanism

Heavy section of wax pattern shrinks as it cools. The volumetric wax contraction during cooling creates a negative pressure and pulls wax surfaces inward.

Description

Defect Type
Negative

Appearance
Smooth, dished surface depression.

Size
Varies

Typical Location
Heavy sections or thick flat surfaces.

Similar to
Dimensional Variation
Aliases
Sink, shrink

Method for defect determination
Visual Inspection, tangential lighting is recommended.

Area	Possible Cause	Potential Correction
Equipment	Out of calibration	See Best Practices Section.
Equipment	High wax temperature	Reduce wax temperature.
Equipment	Low injection pressure	Increase injection pressure.
Equipment	Short injection or dwell time or hold time	Increase time
Equipment	Insufficient wax flow	Increase flow rate.
Equipment	Wax press not suitable for application: improper shot size	If possible, inject pattern on different equipment (liquid, paste or billet).
Equipment	Wax Freezing in nozzle	Increase nozzle temperature +2°F or more above wax temp (especially for paste injection). Contact equipment manufacturer as this practice may cause variation in patterns if small shot size.

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Cavitation
continued

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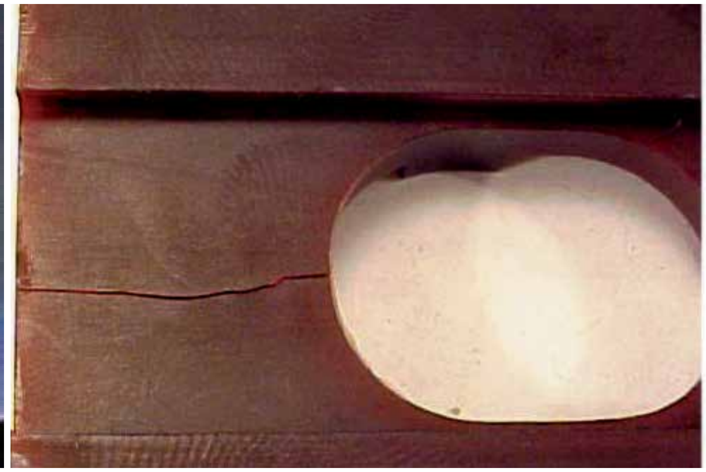
Area	Possible Cause	Potential Correction
Equipment	Filler Settling	Ensure proper conditioning and purging of wax
Pattern Die	Missing wax chill	Create wax chill to reduce the volume of injected wax in the area of sink/cavitation
Pattern Die	Hot Wax Chill	Allow time for the wax chill to cool to room temperature before inserting in the wax injection die.
Pattern Die	Injection runner too small	Increase cross section of injection runner.
Pattern Die	Incorrect injection runner location	Ensure that wax is entering die as close as possible to the largest un-chilled volume section of the pattern.
Pattern Die	Injection runner too long	Shorten the length of the runner.
Pattern Die	Incorrect die temperature	Review die temperature and determine if cooling platen or die would improve condition.
Wax	Wax selection not suitable for application	Consider changing wax to one less prone to sink, cavitation and shrink Consider using wax chills. Consult wax supplier.

Cracking



Mechanism

Release of internal or externally applied stress

Description

Defect Type
Negative

Appearance
Sharp separation, often jagged, often thru all or a majority of the section.

Size
varies

Typical Location
Change in section or area restricted by features of the die or core. Defects often repeat in same location.

Similar to
Knit Lines
Aliases
Method for defect determination
Visual inspection

Area	Possible Cause	Potential Correction
Equipment	Out of calibration	See Best Practices Section.
Equipment	Excessive Injection time	Decrease injection time. If pattern cools excessively in die, it will become hard and brittle and tend to crack before or during removal.
Equipment	High injection pressure pattern difficult to remove from die	Reduce injection pressure.
Equipment	Cold die	Increase die and /or platen temperature.
Equipment	Improper mold opening	Slow down opening rate. Check opening sequence of die carefully without forcing pattern. Note: When draw is deep, make sure parting line is separated evenly. Add or extend guide pins.
Equipment	Improper removal of pattern	Check pattern handling and removal techniques. Consider using air assist

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Cracking
continued

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Area	Possible Cause	Potential Correction
Equipment	Draft, burr or rough surface	Have tool maker check the die. Correct or polish as necessary.
Equipment	Improper adjustment of knock-out pins	Locate pins to avoid a bending stress on the pattern during removal and add more pins if necessary. Check adjustment of pins for even actuation and speed.
Equipment	Sharp inside corners	Check with engineering for possible addition of fillet.
Wax	Brittle wax	Consider changing wax to Increase toughness in order to reduce brittleness. Consult your wax supplier.
Other	Insufficient mold release	Check for adequate mold release in area of difficulty. Change mold release as necessary.

Dimensional Variations

Mechanism

Inconsistent and repeatable variables within process

Description

Defect Type
Shape, Size

Appearance
Very difficult to detect without measurement tools

Size
Varies

Typical Location
Varies

Similar to
Distortion Soluble
Sink
Cavitation
Aliases
Method for defect determination
Visual using inspection measurement tools

Area	Possible Cause	Potential Correction
Equipment	Out of calibration	See Best Practices Section.
Equipment	Injection pressure variation	Maintain consistent injection pressure Note: Low pressure will reduce dimensions. High pressure will increase dimensions
Equipment	Injection time variation	Maintain consistent cycle time. Note: Short cycle will reduce dimensions. Long cycle will increase dimensions.
Equipment	Wax temperature variation	Maintain uniform wax temperature Note: Low temperature will increase dimensions. High temperature will reduce dimensions. Check wax temperature calibration.
Equipment	Die temperature variation	Provide proper cooling / heating to maintain consistent die temperature. Consult with equipment manufacturer if necessary.
Equipment	High nozzle temperature	Decrease nozzle temperature. Note: High nozzle temperature can lead to dimensional variation on small parts due to shot size. Consult with equipment manufacturer.

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Dimensional Variations
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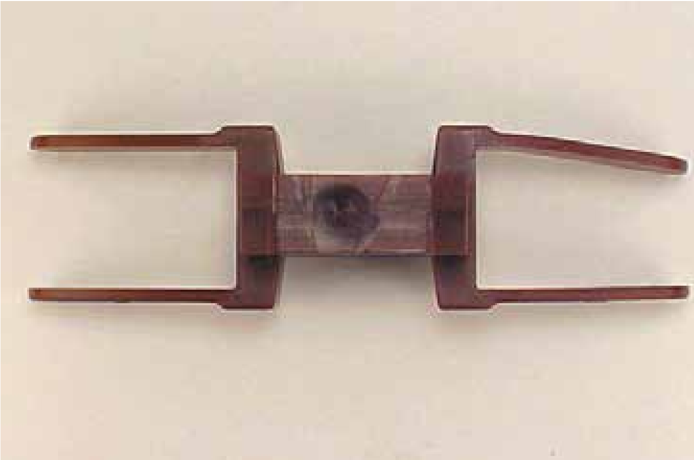
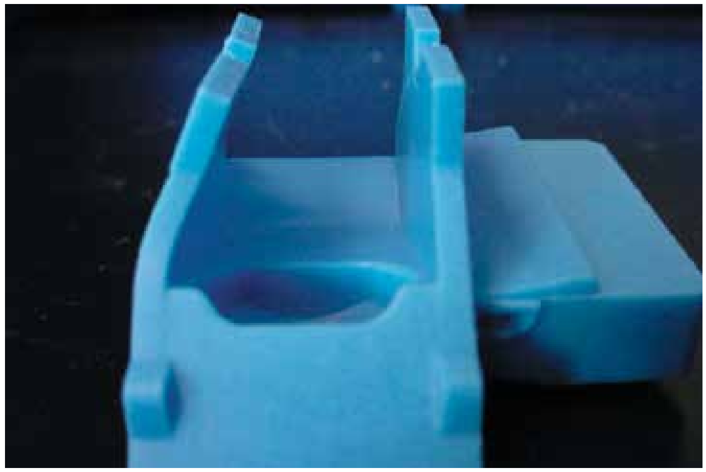
Area	Possible Cause	Potential Correction
Equipment	Clamp pressure variation	Maintain sufficient clamp pressure to prevent opening of die.
Equipment	Uneven clamping of die .	Use proper injection press or balancing blocks
Pattern Die	Runner size too small or improperly designed	Ensure proper size and design of runner system to adequately feed pattern before solidifying.
Pattern Die	Die cleanliness	Clean die as needed and perform routine die maintenance.
Pattern Die	Die mismatch	Check guide pins for wear or proper alignment. Add additional guide pins.
Pattern Die	Die manufacturing errors	Check die dimensions.
Wax	Incorrect shrink factor	Ensure that wax properties are within specifications. For filled waxes ensure proper melting and agitation to maintain uniform filler dispersion.
Wax	Contaminated wax	Check condition of the wax. Replace wax as necessary.
Wax	Filler separation	Use proper conditioning parameters including appropriate agitation in melting tank and in holding tank. Consult wax supplier for proper melting and conditioning procedures.
Other	Ambient temperature variation	Maintain consistent wax room temperature.
Other	Distortion of wax patterns	See “Distortion.”
Other	Missing chills	Ensure that required chills were used.

Distortion





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
Wax Sink

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.
Shell	High strength mold preventing even contraction	Reduce the mold strength.

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Area	Possible Cause	Potential Correction
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

Flash

Mechanism

Wax, under the forces of injection pressure, unintentionally enters thin areas.

Description

Defect Type
Positive

Appearance
Sharp, thin, linear fin of wax perpendicular to the surface.

Size
Varies

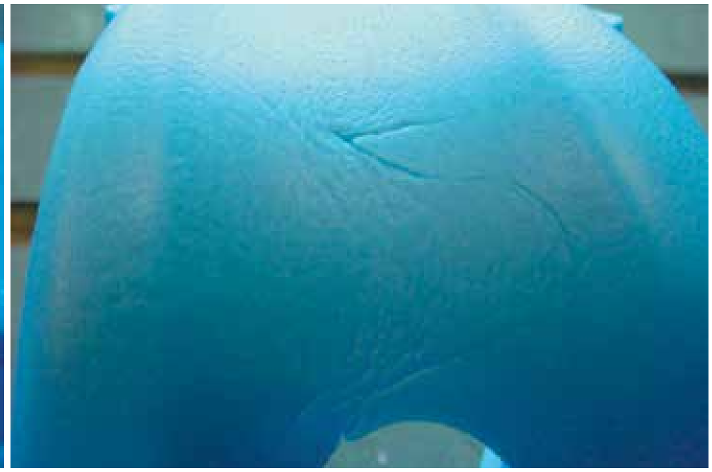
Typical Location
Always at parting lines or interface of cavity and features created by slides, or core prints on soluble or ceramic cores or soluble interfaces.

Similar to
Finning
Aliases
N/A

Method for defect determination
Visual inspections

Area	Possible Cause	Potential Correction
Equipment	Out of calibration	See Best Practices Section.
Equipment	High injection pressure	Decrease injection pressure. Injection pressure can open the die by overcoming the available clamping pressure.
Equipment	Low clamp pressure	Increase clamp pressure.
Equipment	High wax temperature	Decrease wax temperature.
Equipment	Unequal clamping of die	Clamp die evenly. Balancing blocks may be required. Die may flash if it extends beyond the platen plates.
Equipment	Excessive acceleration rate (Machines equipped with electronic injection control)	Reduce acceleration rate.
Pattern Die	Die wear or damage	Correct as required. Inspect for worn inserts or damage due to excessive pressure on die closure. Inspect for worn edges at parting line. Inspect for damage. (e.g. raised impact seams. Review Best Practices to unsure proper techniques.
Pattern Die	Die not completely closed	Remove wax chips or other interference between die faces.

Flow Lines / Knit Lines



Mechanism

Combination of wax viscosity, pressure, and flow characteristics cause interaction with die surfaces

Description

Defect Type
Negative

Appearance
Shallow lines, series of wave-like depressions

Size
Varies

Typical Location
Flat or curves surfaces

Similar to
Aliases
Ripples, wrinkles

Method for defect determination
Visual inspection

Area	Possible Cause	Potential Correction
Equipment	Out of calibration	See Best Practices Section.
Equipment	Cold wax	Increase wax temperature.
Equipment	Wax flow rate	Adjust flow rate as required.
Equipment	Low injection pressure	Increase injection pressure.
Equipment	Cold die	Change die temperature. Turn platen water temperature off or adjust die temperature controller settings.
Equipment	Low acceleration – machine unable to achieve proper flow rate. (Machines equipped with electronic injection control)	Review acceleration setting. Increase acceleration setting to correspond better with wax flow rate. Increase injection pressure to achieve desired flow.
Equipment	Cold wax in nozzle	Increase nozzle temperature to ensure consistency with desired temperature.

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Flow Lines / Knit Lines
continued

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Area	Possible Cause	Potential Correction
Pattern Die	Injection runner design	Review location of runner. Use single injection port and straight and short runners if possible. Complex injection port can prevent proper flow of wax into cavity.
Pattern Die	Poor venting in die	Clean vents or add vents as necessary. Ensure clamp pressure is appropriate – see Best Practices section.
Other	Excessive mold release	Clean die and ensure minimal amount of mold.

Section 2
Defects in Soluble Cores

There are occasions when internal details of a component are created using a core produced from a soluble wax which is commonly referred to as a soluble core. Soluble cores are produced using techniques similar to regular wax patterns and are therefore subject to similar defects.

There are a variety of issues associated with the production and use of soluble cores that can result in defective soluble cores or nonconforming wax patterns.

This section will follow the same format as the aforementioned, except the material will now be specific to the production of soluble cores.

Section 3
Defects in Patterns Related to the Use of Ceramic, Soluble Cores and Wax Chills

There are occasions when internal details of a component are required to be cast around ceramic or soluble cores. It is necessary therefore to inject wax around the ceramic or soluble core during the wax injection process.

There are a variety of challenges associated with this type of process that may result in nonconforming wax patterns or damage to the ceramic or soluble core.

This section will follow the same format as the aforementioned, except the material will now be specific to the use of ceramic or soluble cores.

Helpful Tips

Ceramic Cores

• Make sure that the ceramic core is properly prepared prior to injection.

• Where there are deeper design slots or holes, it is best to fill them with wax prior to injection. This will prevent sink/cavitation in these areas.

• To prevent the wax from lifting from the ceramic core, it may be an advantageous to coat the core with a substance that will promote adhesion.

• For fragile cores that have yield problems:

• Consideration should be given to X-raying cores prior to and after injection to ensure core integrity.

• Prior to injection, do a pre-clamping of the die with core installed. Open die and examine core. If no crack, then continue. If cracked, then check core dimension or the die to see which one is causing the problem.

Soluble Cores

• Make sure soluble cores are prepared properly prior to injection.

• Be sure to completely remove all soluble core pattern material to avoid potential casting inclusions or improperly formed core cavities in the casting.

• Soluble cores will “grow” in size and deteriorate in the presence of high humidity; it is recommended that soluble cores be used as soon as possible after production and stored, if necessary, in a humidity-controlled environment (sealed bag) until used.

• It is important to avoid cross contamination of waxes. To avoid pattern wax contamination with soluble wax, mixing and injection equipment used in interchangeable environments, the equipment that comes in contact must be thoroughly cleaned and flushed prior to completing the changeover. Recommend having dedicated equipment for pattern and soluble wax.

Best Practices

The following are recommendations to prevent wax pattern defects. Evaluation of most defects should begin with a review of the conditions.

Several assumptions regarding Best Practices are made as follows:

- Wax injection machine is of proper size and in good operating condition; all controls such as temperature, injection pressure and flow controls are calibrated (or verified) properly and within calibration time requirements.
- Wax temperature has the greatest influence on wax injection pattern quality so maintaining rigorous controls are critical. Temperature has a great effect on wax viscosity, a measure of flow.
- For temperature measuring devices, the calibration techniques should include the use of boiling and freezing water as calibration points for comparison to calibrated standards.
- Wax temperature at the nozzle should be confirmed using a controlled volume, like a quart cup, and measure the temperature. See example 1 below.

Example 1: Wax temperature measurement at the nozzle tip. First purge the wax in the nozzle then fill at least ½ the volume of a quart cup container. Immediately insert a small tip temperature measuring device that have been calibrated and allow to reach the maximum temperature.

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Definition

Injection Runner
or "runner" is the portion of wax die cavity that begins at the inlet and ends at the part cavity.

Cycle Time
is the time where the injection cylinder is under pressure. This includes filing and packing of the wax pattern.

Hold Time
is the time after the injection cycle. The machine remains clamped but there is no pressure applied to the wax.

Machine Cycle Time
is the total time from open to open of the clamp. This does not include any operator time in between cycles.

Tangential lighting
is when the light strikes the illuminated surface at a very low angle--the light is low to one side of the lighted surface. This is done to enhance any small imperfections on the otherwise flat surface. Shadows from the tangential lighting highlight any small protrusions or shallow contours.

Best Practices continued

• Pressure calibration should be performed by comparison to a certified gauge (see example 2). These gauges can be employed by connecting to a manufacturer supplied calibration point. Calibration points should be close to component being calibrated.

• Timers are verified as operating correctly. Verification is performed by operation in a wide range of time periods with comparison to a known working standard. If there is a question, consult equipment supplier.

• Wax conditioners should maintain temperature at the manufacturer's recommended set point for the reserve tank. Review owner's manual for tolerance of your machine.

• Wax die runner diameters are designed to ensure proper wax feeding during the injection cycle, including the dwell cycle (while under pressure) after the fill of the die cavity is complete.

• Wax is in proper condition and suitable for the application. If there is a question, consult wax supplier.

• Environment is suitable for wax pattern manufacturing, i.e. proper cleanliness, temperature and humidity.

• Ensure the die cavity is clean, and no metal tools are used for pattern removal.

• For issues related to non-fill, flow/knit lines, and air bubbles, it is recommended to use an interrupted injection cycle (or short shot) to examine how the wax enters the cavity. Begin by a start-stop cycle at 1 second, opening the die to examine the order and direction of filling the runner and cavity. Wax temperature has a major effect on the ability to fill the die cavity without defects. This method of analysis can also assist in determining a proper location of air vents by revealing the last area to fill.

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Example 2: A certified gauge can be acquired from industrial suppliers or gauge manufacturers. These are typically oil-filled and chosen knowing the pressure typically measured and assuring the gauge reads this pressure near the mid-point of its display.

Best Practices continued

• Clamping force refers to the force applied to a die by the clamping unit of a wax injection machine. In order to keep the die closed, this force must oppose the separating force, caused by the injection pressure of the liquid wax into the die by the press. Clamp pressure required is a simple calculation using the surface square inches of the cavity and runner open along the parting line of the die. This square inch value multiplied by the maximum expected wax injection pressure (lbs./in2) creates the pounds of downward force necessary to avoid separation of the die halves. Review the equipment manual to understand how the gauge reading correlates into the downward force. It is recommended to use an additional 10% minimum excess downward force.

Example:

1. Determine the total surface area of cavity at the part line.

2. Multiply pressure x surface area to determine force.
Force = Press x Area a. Add approx. 10% to the force.

3. For a cavity 6 x 4 in = 24 sq. in. X 200 psi = 4800 lbf x 1.1 = 5280 lbs. of force is required to contain the wax when injecting at 200 psi.

For a given injection press, how do you know what the force is for the PSI gauge reading?

1. Determine the clamp cylinder size. Bore/diameter is 6” for a 37 Ton machine.

2. Cylinder Size = 6” bore (surface area = 28.27 square inches)
Force = Press x Area 1 PSI on machine gauge = 28.27 lbs. force
Therefore 5280 lbs. / 28.27 lbs. /psi = 187 psi on the machine gauge

List of Defects

Section 1: Defects in Patterns

Section 2: Defects in Soluble Cores

Section 3: Defects in Patterns Related to Cores and Chills

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

Previous List
do we want to include any items from Casting Defects?

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 do we want to include this page from Casting Defects?

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.