AURORA
Casting & Engineering, Inc.

Investment Casting Design Guide

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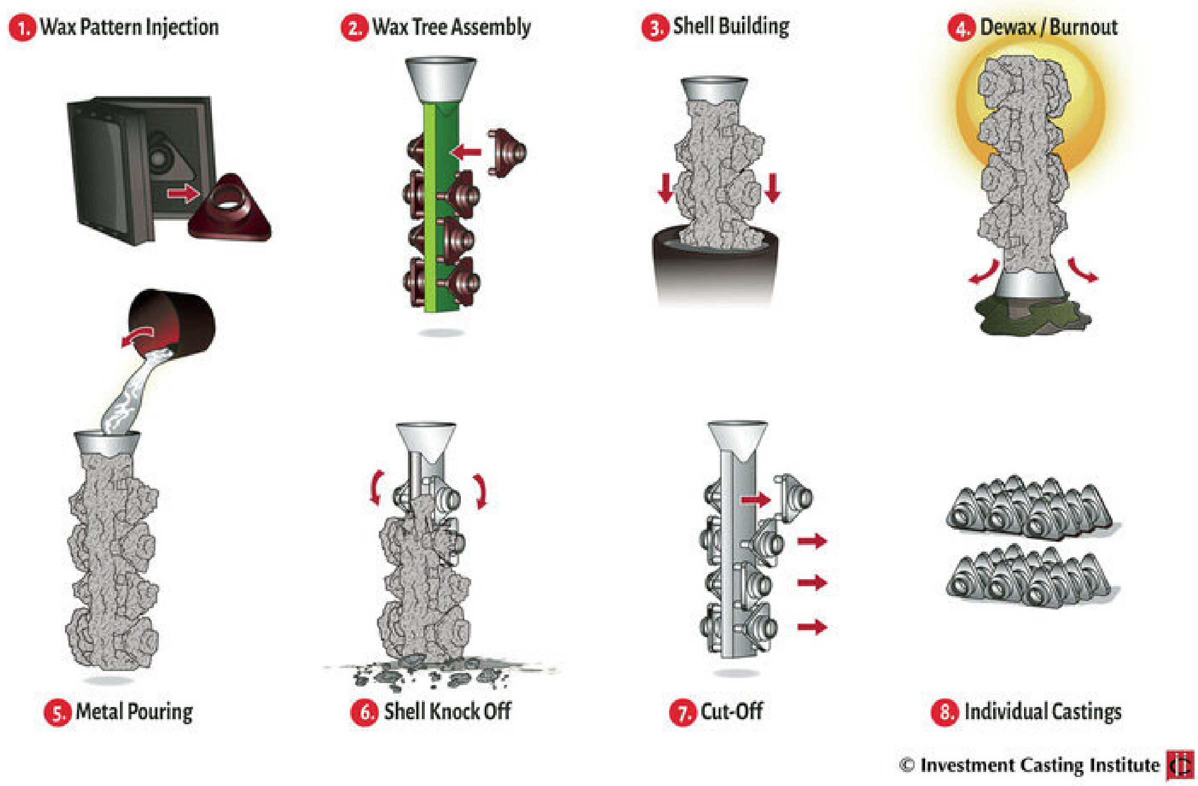
Contents

Purpose and Applications

Investment castings present a cost-effective solution for the manufacture of complex shapes and can improve the affordability, manufacturability, and reliability of the product. Successful casting design requires a specialized expertise and an understanding the foundry process. Aurora will work with your design team to develop a product that meets the all your requirement and is designed for manufacturability.

The Process



Design Freedom - Investment Casting

- Complex geometry
- Combine weldments and assemblies to a single unit
- Reproduce fine detail such as cast raised part numbers, and serrations
- Weight reduction
- Contours and rounded surfaces
- Undercuts
- Near net shape
- Minimal stock allowance
- No draft angle necessary
- Internal configurations, complex coring, and blind holes
- Cosmetic appearance
- Precision tolerances

Material Specifications

- Chemistry testing requirements
- Mechanical testing requirements
- Weld repair allowance/restrictions
- Non-destructive test requirements

Fillets (Inside Corners)

- Added to mitigate a stress riser in casting
- Smaller than .030 fillets increase likelihood of cracks (casting defect) or cracking due to repetitive contact with other surfaces during operation at the next assembly
- Larger than .060 fillet can create a hot spot (casting defect)
- .030 - .060R fillet is optimal
- Fillets should be commensurate with wall thickness

Edge & Corner radii

- Including edge and corner radii reduces frequency of ceramic inclusions and handling damage
- Helps prevent shell bulge at dewax operation
- Eliminates a stress riser
- Minimum of .010 corner & edge radii should always be allowed

Aurora Cast Alloys

Non-Ferrous

- 356 – Most common cast aluminum alloy
- 355 – Higher strength, lower yield, and lower elongation
- F357 – Higher strength, beryllium free
- A357 -Highest strength, contains beryllium

Bronze Alloys

- NiBr & AlBr – Expensive, Material lot charge, High Corrosion resistance

Ferrous Alloys

- 17-4 & 15-5 – Most commonly cast steel alloys
- 300 series
- 400 series
- Low Carbon Alloys

Weld Repair & Hot Isostatic Pressing

Most Material Specifications require Customer Authorization to perform weld repair and hipping (Hot Isostatic Pressing). Aurora recommends the following:

- Weld Repair per AMS 2694
- Hipping

The HIP process subjects a casting to both elevated temperature and isostatic pressure in a high-pressure containment vessel. The chamber is heated, causing the pressure inside the vessel to increase. Pressure is applied to the material from all directions hence the term "isostatic". When castings are treated with HIP, the simultaneous application of heat and pressure eliminates internal voids and micro-porosity (often referred to as “shrink”) through a combination of plastic deformation and diffusion bonding; this process improves fatigue resistance of the component.

Hot Isostatic Pressing per QOP 7540 (Supplier developed specification)

Benefits of allowance include:

- Increase part yields – Parts that do not meet metallurgical requirements can be repaired
- Reduces costs –A lower scrap rate amortized when quoting
- Improves delivery performance – Reduces the need for reruns, and rework operations

Non-Destructive Testing

AMS 2175 Classification & Inspection of Castings

Radiographic Inspection

- Inspection for internal defects
- Performed routinely for Foundry Process Control
- Inspection method per ASTM E1742
- Classifies type and acceptance limits of discontinuities
- Grade A - Highest grade minimum discontinuities, only producible in targeted areas
- Grade B - Allows for some defects, producible, but difficult
- Grade C - High quality, consistently producible
- Grade D - Lowest quality, non-critical castings

Penetrant Inspection

- Inspection for nonvisual surface defects
- Cracks, cold shuts, porosity
- Inspection method per ASTM E1417

Part Marking

Raised cast marking

- Letters, Numbers, Trademarks & Logos
- Part Numbers

Surface Finish

- ANSI/ASME B46.1 Appendix B
- Investment Casting: 60 - 200 RMS
- Surface characteristics should not be controlled on a drawing or specification. Unnecessary restrictions may increase production costs

Casting Distortion and Variation

Castings are never perfectly flat, straight, square, or the same from part to part for many reasons including:

- Wax & metal solidification
- Restricted vs. un-restricted shrink
- Heat treat distortion
- Wax distortion from removal from mold
- General handling distortion
- Repair / rework of casting surface
- Temperature variation
- Production variables

A design language to define features, establish tolerances, and determine inspection criteria has been established in ANSI Y-14.5.

ANSI Y-14.5

The Y14.5 standard is considered the authoritative guideline for the design language of geometric dimensioning and tolerancing (GD&T.) It establishes symbols, rules, definitions, requirements, defaults, and recommended practices for stating and interpreting GD&T (Geometric Dimensioning & Tolerancing) and related requirements for use on engineering drawings, models defined in digital data files, and in related documents.

GD&T is an essential tool for communicating design intent — that parts from technical drawings have the desired form, fit, function and interchangeability. By providing uniformity in drawing specifications and interpretation, GD&T reduces guesswork throughout the manufacturing process, improving quality, lowering costs, and shortening deliveries.

All dimensions must have a tolerance. Every feature on every manufactured part is subject to variation, therefore, the limits of allowable variation must be specified. Plus and minus tolerances may be applied directly to dimensions or applied from a general tolerance block or general note. For basic dimensions, geometric tolerances are indirectly applied in a related Feature Control Frame. The only exceptions are for dimensions marked as minimum, maximum, stock or reference. Dimensions define the nominal geometry and allowable variation.

Engineering drawings define the requirements of finished (complete) parts. Every dimension and tolerance required to define the finished part shall be shown on the drawing. If additional dimensions would be helpful, but are not required, they may be marked as reference.

Dimensions should be applied to features and arranged in such a way as to represent the function of the features.

Datums

Thus, A theoretically exact point, axis, line, plane, or combination thereof derived from the theoretical datum feature simulator. Datums provide a structure for consistent measurement and a common starting point for secondary operations. Datum Points should be spread to the extents of the casting

- Minimize multiplying the effect of minor surface distortions
- Datum Points should be placed on cast surfaces not subsequently machined
- Datum Points should be co-planer surfaces
- Rigid areas of the part that are restrained from movement
- Avoid isolated heavy areas or thin edges.
- External surfaces
- Centralized Datums - Centralizing the datums shortens the longest dimension from 0,0,0

Tolerance

Investment Casting Tolerance		
Feature Size/Location	Standard	Premium (Specific features can be held to a tighter tolerance)
<1.000	.010	.005
<2.000	.013	.007
<3.000	.016	.009
<4.000	.019	.010
<5.000	.022	.012
<6.000	.025	.014
<7.000	.028	.016
<8.000	.031	.018
<9.000	.034	.020
<10.000	.037	.022
>10.000 allow for +/-.005 per inch		

Premium Linear Tolerances -All three sources of variation can be reduced by:

- Including addition of tie bars, ribs, and gussets to contain shapes.
- Tuning of wax injection tooling after the first sample to meet nominal dimensions.
- Straightening fixtures
- Additional inspection/gaging
- Machining

All of these can assist in obtaining tighter-than-normal tolerances. Premium tolerance on features must be considered on a part-by part, dimension-by-dimension basis. This will be a cost driver.

Blind Holes & Pockets

In blind hole design, large corner radii blending from the part surface to the hole are necessary to provide adequate core strength. Bottoms of blind holes should be full round or radiused as much as possible. Blind holes may be cast to:

Size	Max Depth	Corner Radii
.040" - .120	.5 x hole diameter	.5 x hole diameter
.121" - .400	1 x hole diameter	.060" - .090"
.401" +	2 x hole diameter	.091" - .180"

Ceramic cores can be used to allow greater blind hole depths but add significant cost to the casting.

Through Holes and Cores

Through holes and cores can be produced by multiple methods such as:

- Soluble and shell
- Soluble and core pack
- Ceramic cores and leach

Core length is limited by the diameter of the core. If a longer core is required, core support holes may be added and subsequently welded closed. Core supports which require welding will either have lack of penetration or drop though. If cores are not straight the length may be limited. Cores should not bend with a radius tighter than the diameter.

Diameter	Core Length
.040 - .125	5X Diameter
.126 - .750	10X Diameter