Design considerations

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Precision Investment Castings

Why choose investment casting?

- Over the years the process has been continually revised.
- Driven by technology advances it has become one of the most versatile choices available.
- It offers a great combination of complex geometry, high strength materials, and lightest weight for a given envelope.

Overall process is complex

- From the design release the path to success can be a long one.
  - Tool build or 3-D printed patterns?
  - CAD files significantly help the process
    - Volume requirements come into play
    - Gating complexity and dimensional shrink factors can be refined by using 3-D printed patterns

Tooling

- Shape drives tool design and costs
- Parts with passages require more complex tooling
- Casting alloy choice can dictate what approach is best
- Part applications can mandate approach
  - Turbine blades

Tooling approach

- Each foundry will leverage their particular expertise
  - Straight dipping
  - Pre-formed ceramic cores
- Cost can come into play as well
  - Ceramic core dies have a premium price due to the need to survive injection of abrasive materials

What we are looking for in the design

- In the most basic terms:
  - Smooth designs with a minimum of abrupt section thickness changes
  - Generous fillet radii
  - Edge and corner radii flexibility to facilitate tool build
    - Edges possibly sharp locally
    - Corners large enough to allow larger cutters in die construction

Most basic design items

- Open dialogue on wall thickness
  - Alloy choice will drive the long term capability of the process
  - Air-melt and vacuum casting have different capabilities
  - Aluminum and steel are radically different
  - Stainless alloys don’t flow as well as nickel-based materials
- Wall span is a key consideration in all of these

Most basic design items

- Isolated masses require special attention
  - Tool design
  - Gating and mold assembly
- Deep pockets create localized solidification issues
  - Entrapped energy overheats edges of the shell and can create open shrinkage in fillets.
  - Larger fillet radii can help
  - Making pockets through-wall helps cooling

Close proximity masses

- As with deep pockets, large masses in close proximity can influence each other during solidification.
  - “Radiation cross-talk” can disrupt the normal direction and timing sequence of liquid to solid transition
- Joining features can help
  - Adding webs gives better feeding to both
  - Obviously weight has to be considered

Round and flat never are…

- This is an injection molded product
  - Material is wax that is pliable
  - Part distortion due to handling possible
- Wax formulations vary from one foundry to another
  - Filled waxes are more ridgid
  - Non-filled formulations are more pliable however they are easier to evacuate with less residue
- Solidification stresses come afterwards

Do we need draft?

- Sometimes, but it's never like sand castings or forgings.
- Often draft angles of ½° per side are sufficient
- Draft should always be considered as additional material

Cast holes or machine them?

- The answer is that it depends on the:
  - Size of the holes
  - Blind or through-going
  - Positional tolerances
    - Individual feature or part of a bolt circle
- Subsequently tapped holes should be machined
- Blind holes in bosses can create problems in shelling and in NDT

Welding allowance

- The need to weld is driven by a variety of issues and they can vary from part to part and by operation.
- NDT grade parts see more welding because they are subjected to higher scrutiny.
- A lot of what is welded is surface indications

Surface indications

- As performance requirements increase there is a corresponding tightening of cosmetic standards.
  - Pits (small oxide inclusions or gas)
  - Flow lines (wax injection knit lines or oxide interaction lines in metal)
  - Knicks, scratches
  - Roughness
    - Metal burning into shell

Surface indications

- For the most part, visual defects will pass NDT inspection via penetrant and magnetic particle testing.
- The visual standards however mimic the NDT criteria and even though FPI/MPI might accept them, they are rejectable under visual guidelines
- Good practice suggests that visual criteria be questioned for value

Should we HIP these??

- Hot Isostatic Pressing is a powerful tool to consider.
- Component density becomes more reliable with HIP processing.
- HIP can close small voids that are undetectable via X-ray
- Increased yields at the foundry and the machining operation are possible

HIP can’t solve all problems

- HIP works with high temperatures and very high argon gas pressures
- Gas pressure differential must exist between the outer skin and whatever internal void exists
- If the void is connected to the surface the process will not achieve compression
- It will not close or alter entrapped material (ceramic, dross, tungsten)

HIP downside

- Added cost
  - Specialized equipment
  - Limited sources
  - Longer lead times
- Surface depressions can be created during HIP closure
- Dimensional issues can result **BUT** if parts would have failed X-ray they would be ground and welded anyway

Should we HIP these?

- There are many benefits to HIP and in the end it has to be a question that is addressed by the customer and the foundry.
- It does not enhance mechanical properties beyond what the material can normally achieve
  - It reduces the low end results and elevates the averages

Measurement and qualification

- We have come a long way from surface plates and scribe lines
- New technologies are coming every day.
- CMM’s were considered high technology not long ago.
- Today light scanners can do amazing things
- The technology will continue forward

Future snapshot

- Castings are better understood
- CAD has opened the doors for more accuracy in tooling and has reduced costs making castings more affordable
- Quality systems (AS-9100 and Nadcap) = standardization
- Equipment is becoming better
- Automation will benefit manufacturing
- **<u>The bright minds of today keep us moving</u>**

Thank you for your attention

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