Liquidmetal Design Guide

Liquidmetal Technologies[1]

Why Liquidmetal Alloy?

Liquidmetal alloy is a revolutionary metal combining the superior mechanical properties of a metal and the processability of a plastic. When molten, it can be injection molded, allowing for Liquidmetal parts to be made at production volumes and with the consistency common for plastic parts with a superior metal result. Once solid, Liquidmetal is stronger than titanium, high hardness and yield strength and has a beautiful metallic as-cast finish. With Liquidmetal's process, small metal parts can be manufactured at costs lower than can be achieved by traditional CNC machining. At the same time, Liquidmetal parts have superior mechanical properties to parts made with traditional die-casting, powder metal, or MIM (Metal Injection Molding).

Our Process

Understanding how Liquidmetal is processed will help designers create designed-for-Liquidmetal parts.

Liquidmetal is processed in the following steps:

- A 100 gram rod of solid Liquidmetal is heated up to its melting temperature in an injection molding machine.
- A plunger tip pushes the molten metal into a standard two-piece tool steel mold with cavities the shapes of the parts being manufactured.
- The Liquidmetal mirrors the shape of the part cavities and then cools in the mold forming solid amorphous parts.
- The mold opens and ejector pins push the metal parts out of the mold.
- The parts are post-processed (de-gating, de-burring, blending, polishing, blasting, etc.) into their finished form.

Disclaimer: This Liquidmetal Design Guide is subject to change and update at any time without notice and any errors are subject to correction without liability

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Our Material

Liquidmetal currently manufactures their components from an alloy called LM-001b. This is a primarily Zirconium based alloy which contains 5 different elements: Zirconium, Titanium, Nickel, Copper, and Beryllium.

Mechanical and Physical Properties

Yield Strength	1900	MPa
Hardness	550	Vickers
Density	6.03	g/cm3
Impact Strength	8	J/cm
Fracture Toughness	55	MPa√m
Elasticity	2.0	% original shape
Young's Modulus	93	GPa
Specific Strength	311	kNm/Kg
Poisson's Ratio	0.39	

Electrical and Thermal Properties

Specific Heat Capacity	420	J/Kg°K
Thermal Expansion	10.1	µm/m°K
Thermal Conductivity	6	W/m°K
Electrical Resistivity	190	µΩcm

Figure 1: LM-001b material properties

Parts Suited for Liquidmetal

Liquidmetal's current manufacturing process is well suited for smaller complex parts. Our process is the most cost effective for small, intricate metal machined components that require medium to high volumes. In traditional machined components, each feature adds an incremental cost to the total price of the final part while in our process this is minimized as it is simply a feature replicated from the mold.

The design and complexity of a part greatly influences the ease of manufacturing and number of cavities possible in a mold. Please contact us with your CAD models for a quick review. We utilize native Solidworks and also work with STP or X_T parasolid files.

Design Principles

Tolerances

Actual tolerances are highly dependent on specific part geometry and features such as wall thickness transitions. Both standard and precision tolerances follow the rules laid out by NADCA in their publication *Product Specification Standards for Die Castings*. Precision tolerances will result in higher pricing and should only be specified when and where required. Tolerances which are even more precise than the "precision tolerances" can be achieved through special procedures (post-processing procedures). Due to low shrinkage rate of our alloy, it is more likely to meet your part requirements than other die-cast parts.

See below for a list of the tolerances typically held by our as-cast products.

Dimension	**Metric**	**Imperial**
Standard Linear Features	±0.125mm up to 25.4mm	±0.005" up to 1.0"
	±0.025mm for each additional 25.4mm	±0.001" for each additional 1.0"
Precision Linear Features	±0.025mm	±0.001"
	±0.025mm for each additional 25.4mm	±0.001" for each additional 1.0"
Parting Line Thickness	+0.05mm (additional)	+0.002" (additional)
Parting Line Shift	+0.05mm (additional)	+0.002" (additional)
Flatness	0.05mm	0.002"
Straightness	0.05mm	0.002"
Circularity	0.05mm (f to parting line)	0.002" (f to parting line)
Angularity	0.001 mm/mm	0.00004 in/in
Concentricity	0.05mm (f to parting line)	0.002" (f to parting line)
Surface Finish	0.05-0.1 microns (depending on mold finish)	2-4 μin (depending on mold finish)

Figure 2: GD&T chart for Liquidmetal products

Shot Size

Currently Liquidmetal loads its machines with 100 gram ingots. 20-30 grams of Liquidmetal is used up by the runners of the part, leaving 70 to 80 grams for the parts themselves. The density of Liquidmetal is **6.04 g/cm^3**, which results in a maximum part volume of 11 to 13 cm^3.

DENSITY (g/cm^3)				
Liquidmetal	Magnesium	Aluminum	Titanium	Stainless Steel
LM-001b	AZ-91	380 Series	6Al-4V	17-4
6.0	1.8	2.8	4.4	7.7

Figure 3: Density comparison between competitor materials

Liquidmetal's cost per shot is fixed, but the number of parts that can be fit into a single mold cavity is variable. If parts are smaller, more parts that can be filled in a single shot, thus reducing the cost per part. If the part is using most of the available material contained in a single ingot, then it is likely to cost significantly more than a smaller part that can be cast into many cavities in a single shot. This is why smaller, more intricate parts tend to provide the biggest cost benefit for customers interested in manufacturing from this alloy and process.

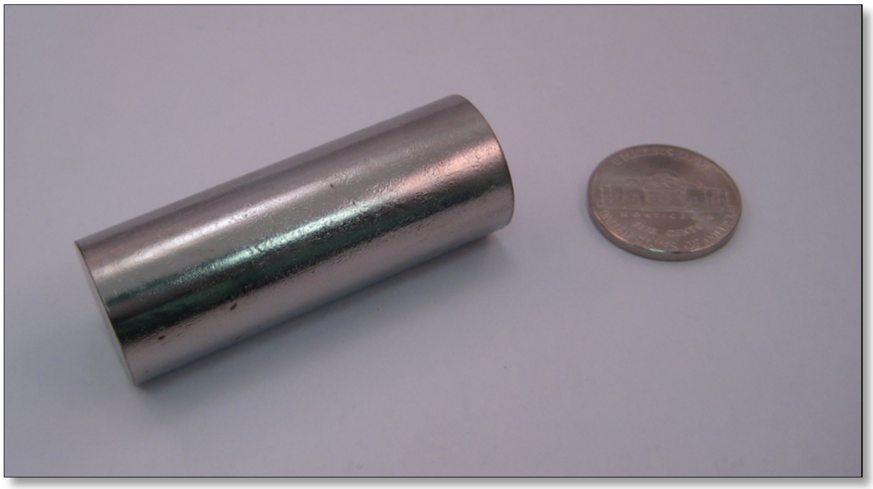


Figure 4: A picture of a raw Liquidmetal ingot before processing. A nickel is shown for scale. This ingot is the maximum amount of material a single Liquidmetal part can be made with.

Wall Thicknesses

Picking a wall thickness of a designed-for-Liquidmetal part involves a tradeoff between producing the highest-quality material (fully amorphous) and being able to fill the mold cavity completely.

Liquidmetal's excellent mechanical properties depend on the Liquidmetal cooling quickly in the mold cavity. If the part cools quickly enough, the part will retain an amorphous structure. If cooled too slowly, the core of the part will crystallize resulting in inferior mechanical properties.

Thinner walls cool most quickly in the mold and are more likely to be fully amorphous. At the same time, if wall sections are made too thin, then the part cavity will be difficult to fill completely. Thinner sections are harder to fill because the metal has to squeeze through a very small space, cooling faster and possibly solidifying before the end of the part is reached. Thin features (less than 1.0 mm) can be filled, but over shorter distances than thicker sections can be. Very localized regions down to 0.4mm are possible but must be reviewed by Liquidmetal engineers to ensure that filling them is possible.

Liquidmetal performs a flow simulation for every part cavity prior to entering production. Most parts which are of a suitable size for Liquidmetal are able to fill without difficulty. Simulation results are most often used to design an optimal cavity layout and to determine the number of part cavities that can be included into a given mold.

Draft Angles

All liquidmetal parts require draft angles on faces parallel to the draw of the mold. These angles are necessary for the part to be able to release easily from the mold. Outer faces require less draft than inner faces because the parts shrink a very small amount during cooling, tending to pull away from outer mold walls and grip inner mold walls. In general, Liquidmetal Technologies recommends a minimum draft of 3º on all internal surfaces and a minimum of 1.5º on external surfaces. In certain situations, draft angles may be decreased but it must be absolutely necessary and should be discussed with a Liquidmetal design engineer to get approval.

The larger the part in the Z-direction (parallel to the pull), the smaller the draft angles can become. For die-casting alloys, there is a general rule that applies to draft requirements based on material. Below is such a table with Liquidmetal's alloy included.

Alloy Group	Inner Surfaces	Outer Surfaces	Hole (total)
Zinc and ZA	50	100	34
Magnesium	35	70	24
Aluminum	30	60	20
Copper	25	50	17
Liquidmetal	*15*	*30*	*10*

Figure 5: Comparison of draft angle requirements for Liquidmetal compared to other die-cast alloys. The C value is a dimensionless number that generates a suggested draft angle based on the depth of the wall that is being drafted.

Depth, L (mm)	Draft (degrees)
0.5	5.4
1	3.8
2	2.7
5	1.7

$$Draft\ Angle = \frac{57.2738}{C\sqrt{L}}$$

Figure 6: An example of the draft angle that would be required for an inner surface of a Liquidmetal part based on wall depth.

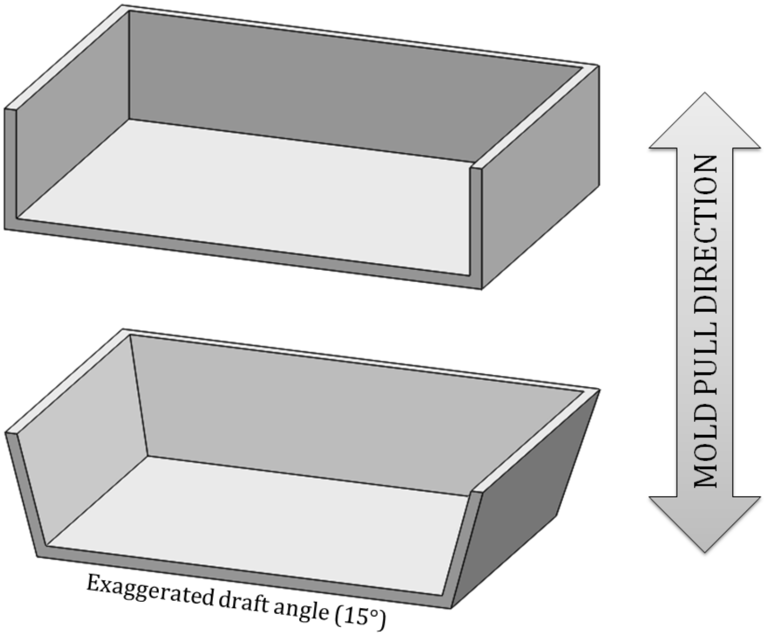


Figure 7: Top image is an example of a part lacking draft and improperly designed; bottom image shows part with draft angles included.

Undercuts

Liquidmetal is able to cast external undercuts through correct positioning of the parting line. A mold slide can also be used to produce some types of external undercuts. Some parts, however, have internal undercuts which prevent them from being cast in a two-part mold. We recommend that internal undercuts be eliminated from designs. In some instances, undercuts can be produced by a secondary machining operation which adds cost to the part. When slides are used, the design should allow them to be located on the die parting line.

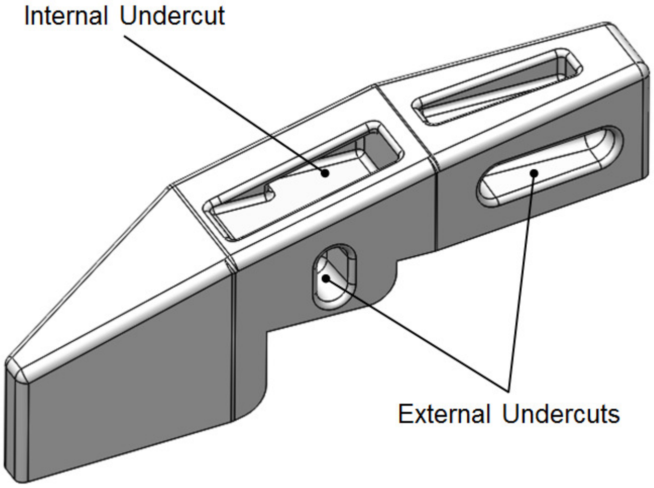


Figure 8: Simple example of a part that has internal and external undercuts. The external undercuts can be included into the part using a slide core while the internal undercut would require a secondary machining operation to get a similar geometry. Internal undercuts should be avoided.

Parting Lines

Where the two halves of the mold meet is known as the parting-line. Placement of the parting line relative to the part is crucial for making the part moldable and the resulting part functional.

During molding, a small cosmetic line is created along the parting line known as the witness line. The position of the witness line should be selected so that it does not interfere with the part's function or aesthetics.

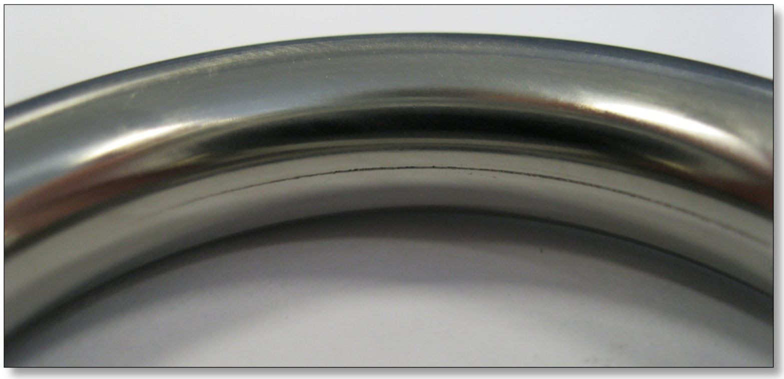


Figure 9: Example of a witness line on a ring-shaped part from where the two sides of the mold meet.

Ejector Pin Witnesses

To release from the mold most parts are pushed out by small pins called ejector pins. A small circular witness mark is left where the pin contacts the part, known as an ejector pin witness. When designing the mold for your part, Liquidmetal Technologies can advise you on the best placement of ejector pins to minimize their cosmetic and functional impact. Some simple parts can be made without ejection, but require more draft so that they can be released easily from the mold.

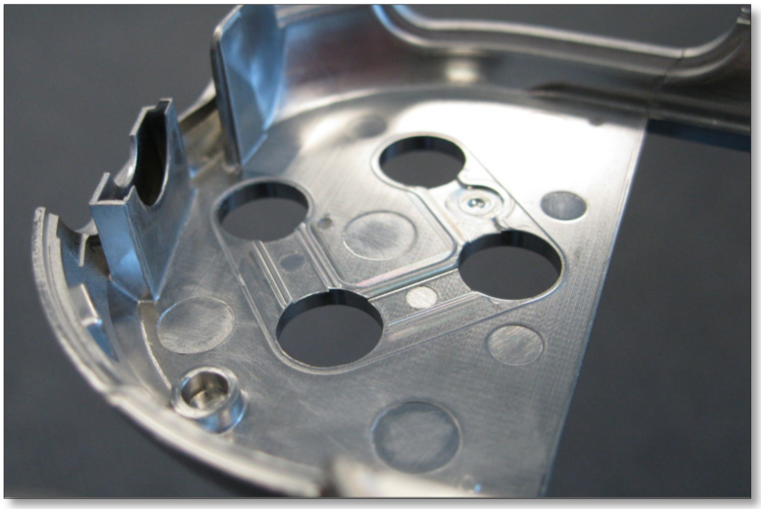


Figure 10: Example of ejector pin witnesses on the non-cosmetic underside of a part.

Fillets and Radii

Sharp external corners are often mandatory at the parting line locations and mold component intersection. In all other cases, radii should be applied to the edges of the part. The minimum radius which can be used on in our manufacturing process is 0.25mm. If possible, it is extremely helpful if this can be increased as it can only help with material flow through the mold. Internal edges of the part should contain fillets as well and while these can be down to 0.10mm, it will help tool life, aid in release of the part from the tool, and improve the surface finish of the final part. Keep in mind that the larger the radii and fillets can be in these regions will also help to strengthen the part by eliminating stress risers.

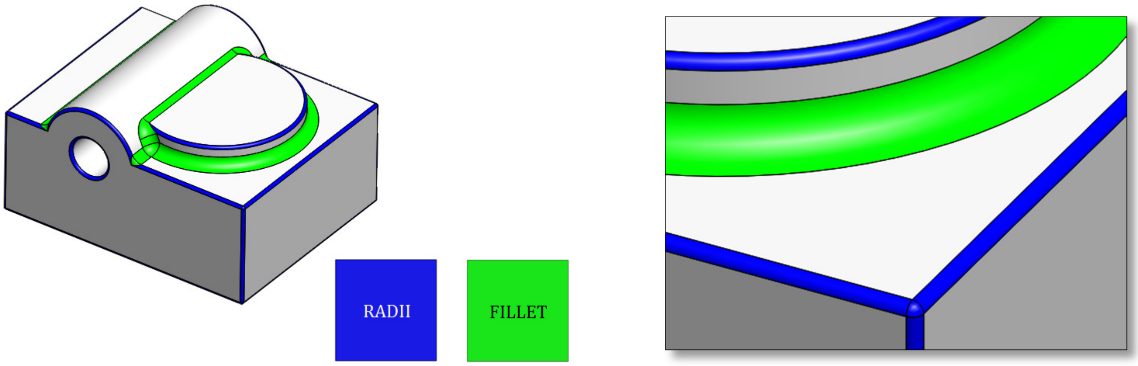


Figure 11: Examples of radii and fillets

Cored Holes

These can easily be achieved while producing Liquidmetal parts; however, care should be given to keep cored holes as large as possible. The smaller the diameter and the deeper the cored hole will cause an increase in the need for tool maintenance and potential for production down-time. This will inevitably increase the cost of manufacturing.

Long, fragile cores tend to warp or break under continuous use due to the heat and pressure of their operating environment. The size of the core pin, and thus the diameter of the hole, should therefore be maximized whenever possible, particularly at the base, to ensure the stability of the pin. A useful rule of thumb to remember when designing part holes is the "2:1 rule": The height of the hole should not be more than twice its diameter.

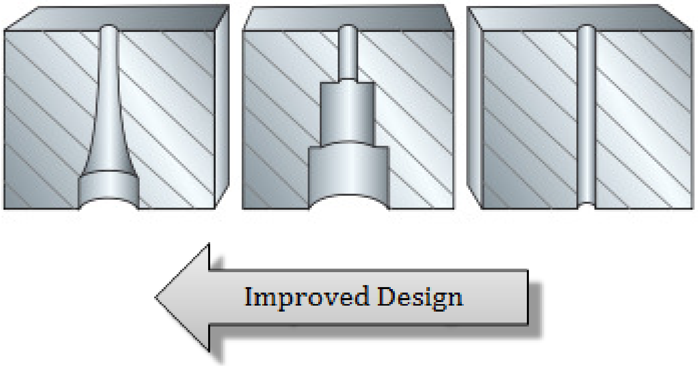


Figure 12: Preferred core pin design starting from left to right

Machining Stock Allowance

Although machining of Liquidmetal parts is not recommended, if it is necessary to remove material from the as-cast part, the additional material added to the surface should be 0.25mm. Allowance must be made for all molding tolerances. Preferably, the datum structure which is used to locate the part for machining should be on the same mold half as the feature to be machined.

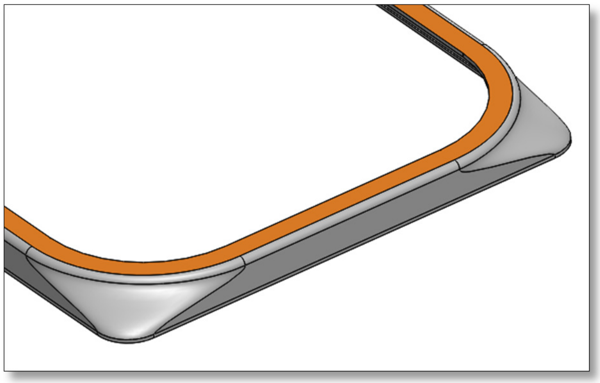


Figure 13: If a surface requires machining to reach a precision flatness or parallel tolerance, additional stock equal to 0.25mm should be added.

Runners and Gates

Liquidmetal requires channels to flow through to get from the entrance of the mold to the part cavities. These channels are known as runners and where the runner meets the part is known as the gate. Once the part has cooled in the mold, the gate is removed from the part with a water-jet cutter or wire EDM. Often the best gating locations are large flat sides of parts. Figure 3 shows a model of a mold cavity as an example of runners and gates.

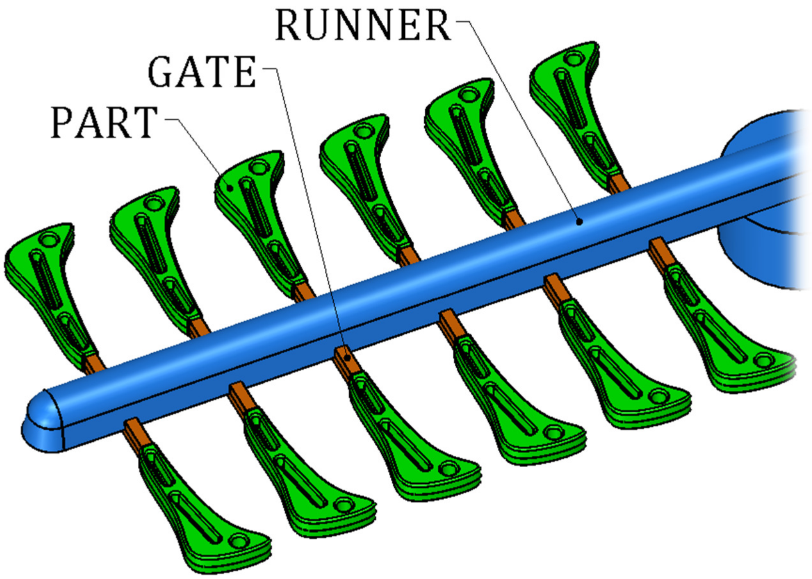


Figure 14: Example of a part tree showing the parts, gates and runners. Selecting a gate location is important to making sure that the part can be de-gated cleanly and cast in an efficient layout.

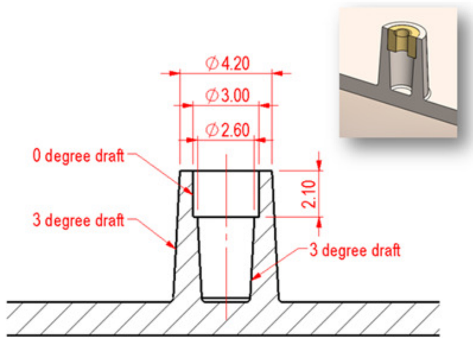
Internal and External Threads

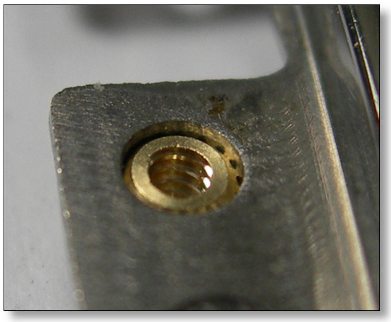
Liquidmetal Technologies can produce external threads in an as-cast part. For a thread to be generated by the casting process, the mid-plane of the thread must sit along the parting line of the mold. To ensure that the witness line does not interfere with the thread, Liquidmetal recommends that threads be removed on the parting line such that there is a 3 degree draft on those flat faces of the part. The figure below shows an example of how an external threaded part can be made with Liquidmetal.

Figure 15: An example of a threaded part that can be made with Liquidmetal. The threads are removed along the parting line to eliminate undercuts and to prevent the parting line witness from interfering with the threads.

For internal threads, the part needs to be designed with a boss that can accept a brass nut insert that can be physically pressed in place during the part finishing steps after the casting process. Liquidmetal has made many products with this feature and it has proven acceptable in a wide range of products requiring some minimum spec on the pull-out forces (>20 Kgf). The brass nut insert is pressed into a hole in the Liquidmetal product that generates a friction fit between the brass and Liquidmetal. An example of the boss design and general dimensions for various thread sizes are shown below.

M1.6 Insert Boss Design in Liquidmetal Product





Thread	M1	M1.2	M1.6	M2	M3	M4
Boss OD	3.6	3.8	4.2	4.6	5.6	6.6
Boss ID	2.2	2.4	3.0	3.4	4.4	5.4
Insert Nut OD	2.2	2.4	3.0	3.4	4.4	5.4

Surface Finish

Liquidmetal can apply a variety of finishes to parts. The various surfaces range from as-cast (which is preferred by many customers for its natural metallic finish), tumbled and sand-blasted to polished, painted and plated. Finishes with greater complexity tend to cost more as the primary driver of cost associate with these treatments is the time spent in producing them. In addition to this, a polished finish will cause minor defects to show much more readily which will result in a drop in yield rate and in the end a part that is priced higher. Liquidmetal has the rare ability to generate as-cast surfaces with surface roughness from 2-4 μin (0.05-0.1 μm). Typical die-cast products range from 32-63 μin (0.8-1.6 μm).

Figure 16: Example of lustrous as-cast finish

Shrinkage and Sink Marks

When comparing Liquidmetal to plastic injection molded components, the shrinkage is negligible at around 0.3%. Depending on the part geometry, it is possible to see sink marks on the final part so there are certain steps that should be taken to avoid this.

1. Design the part with as nominal a wall thickness as possible.
2. Design the part so that as the material flows into the part geometry, it fills from the thick sections to the thinner sections of the part.
3. Gradual transitions from thick to thin sections, including generous radii and fillets.

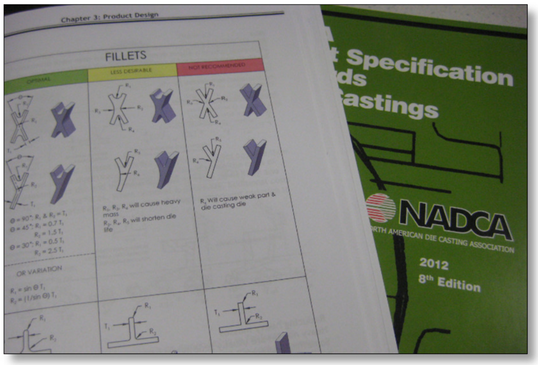


Figure 17: Guidelines for design of die-casting products can be found from NADCA to help optimize part design

Simulation Capabilities

Liquidmetal routinely performs flow simulations in order to optimize mold designs (runners, gates, number of cavities) and to make sure that parts fill correctly and without defects. The simulation program that is used (Flow-3D) has been catered specifically to match our material properties in the molten state. Liquidmetal has a unique viscosity throughout its processing range that makes filling of the mold occur much differently than typical die-casting alloys.

In fact, it actually processes much more similarly to plastics than metals which is one of the reasons that an injection molding machine (with precision injection velocity and pressure) is used to manufacture Liquidmetal's current product line.

Taking all of this into account, Liquidmetal can accurately predict the chance of filling a thin section in a complex part, track the probability of surface defects caused by flow issues, predict areas of tool wear over time, find the region of the part that will fill last and thus add an overflow in the correct location if necessary, determine part geometry that could cause unwanted turbulence, look for areas of potential part crystallization due to heat retention, and many more advanced techniques to avoid problems that could occur during production. All of this allows Liquidmetal to manufacture a high quality bulk amorphous alloy product the first attempt.

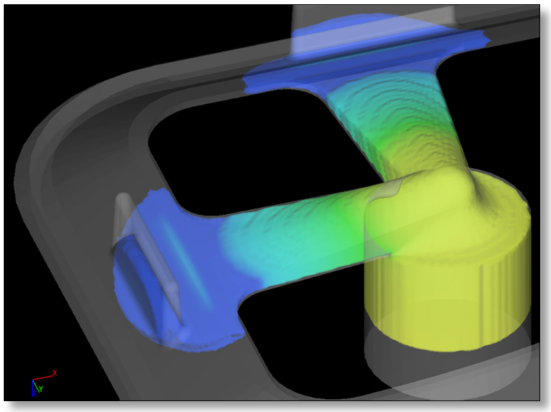


Figure 18: Design for laminar flow

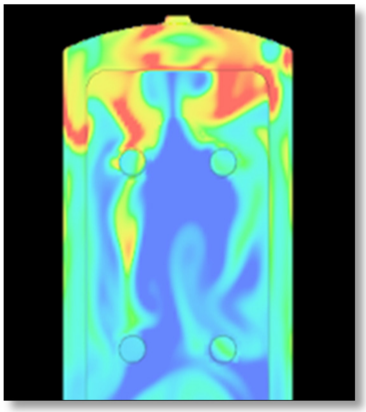


Figure 19: Surface defect tracking

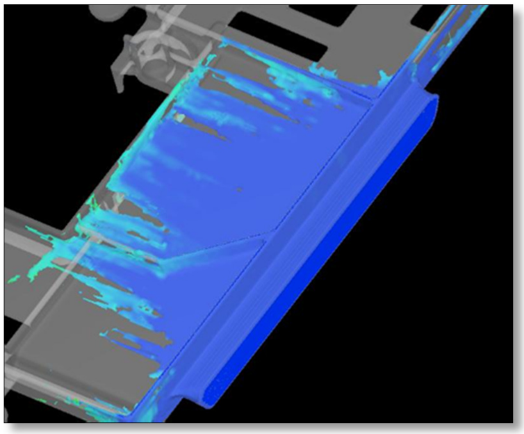


Figure 20: Flow turbulence prediction

Liquidmetal also has the capabilities to perform mechanical simulations to ensure that parts meet targeted mechanical specifications before they are manufactured. These are completed using FEA software powered by ***SolidWorks***.

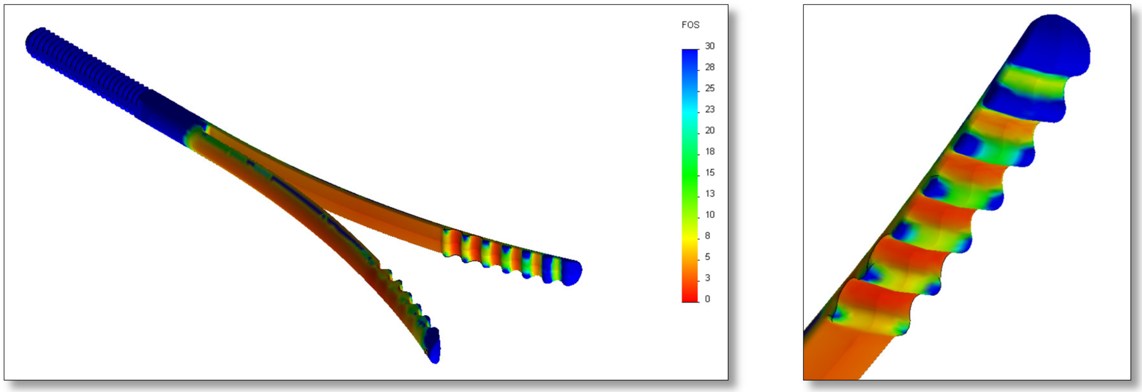


Figure 21: FEA simulation capabilities

Contact Us

If you have a part that you are considering making with Liquidmetal, contact us today. Our engineers would be happy to speak with you about your application and help you prepare a designed-for-Liquidmetal part.

Contact Information:

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