MACHINE DESIGN

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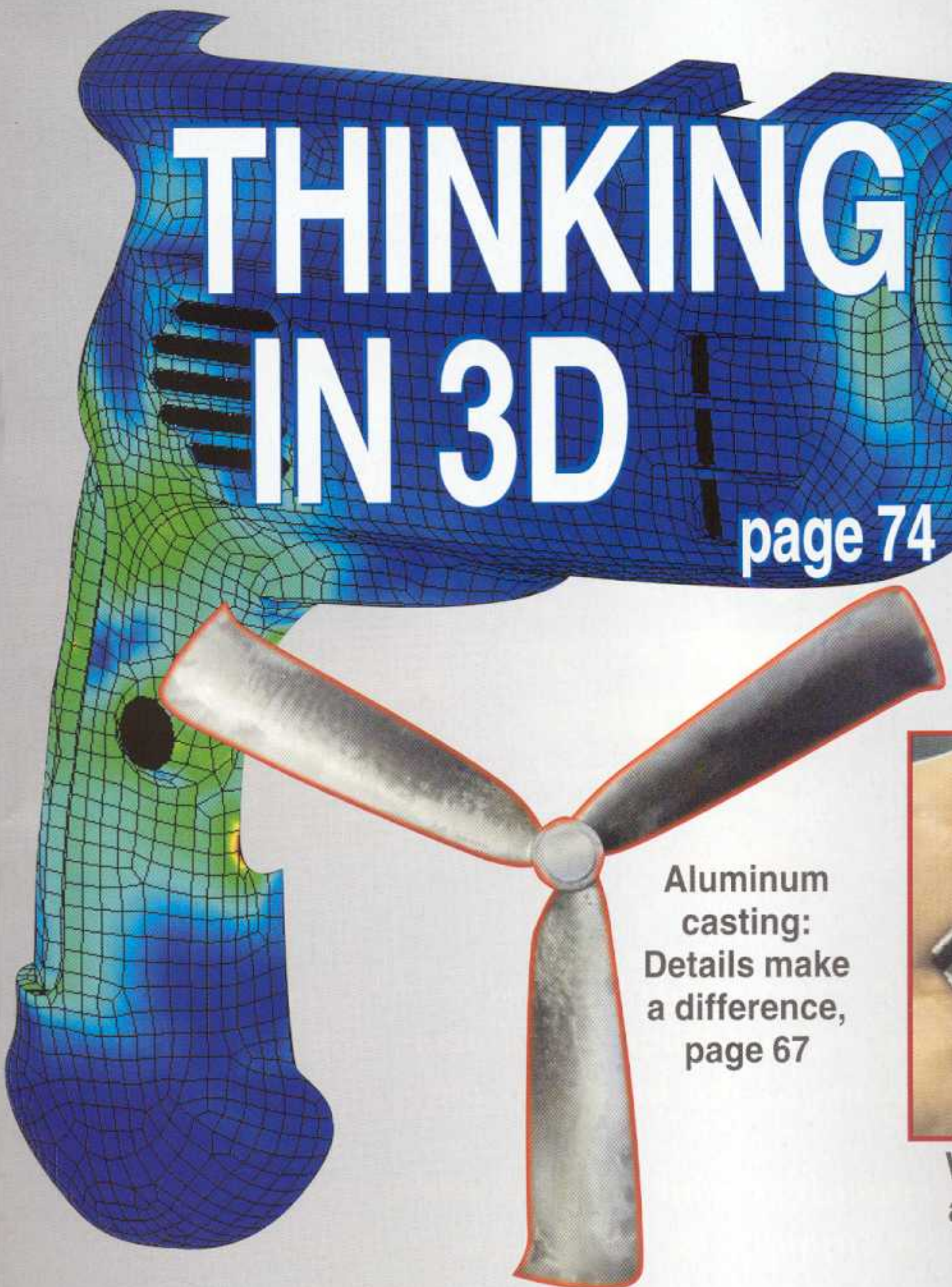

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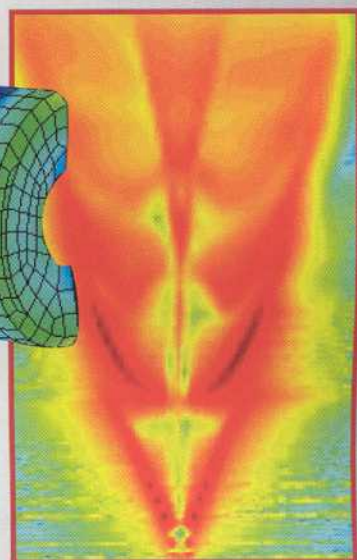

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A better way to cast aluminum

Gravity casting aluminum in permanent molds beats conventional sand and pressure die casting.

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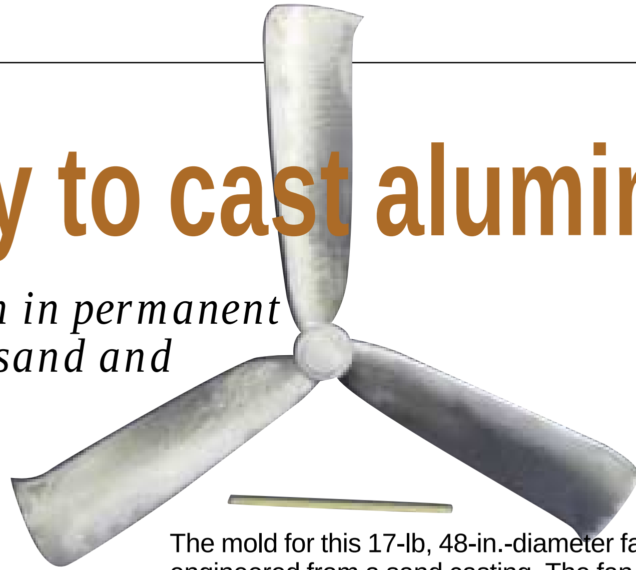


The mold for this 17-lb, 48-in.-diameter fan was reverse engineered from a sand casting. The fan used in an agricultural application is cast in one piece. The high repeatability of the permanent-mold casting process helps minimizes secondary machining operations and spin balancing processes.

Today, gravity-fed permanent metal molds can produce near-net-shape parts from a variety of aluminum alloys. But it's up to the designer to makes sure it's both possible and profitable to use permanent molds to produce the part. Knowing the limits of this casting process can help designers create parts that take full advantage of this proven manufacturing process.

The process

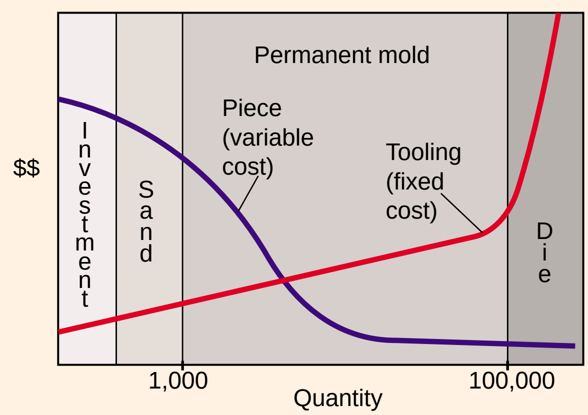
Permanent molds produce large numbers of dimensionally repeatable parts using molds machined from cast iron or steel. In contrast, investment and sand-cast molds are destroyed during part removal and during die casting, molten metal is injected into dies under extremely high pressures. Consequently, dies must be designed to withstand these pressures which drastically boosts cost compared to gravity-filled permanent molds.

Permanent-mold castings can be made with uniform nonporous microstructures, but these qualities are highly dependent on solidification rates and foundry tooling designs. Molds must be carefully designed with sprues, vents, and risers all working in tandem so the metal completely fills the mold under smooth controlled flow.

Design and placement of sprues and gates are critical to help ensure controlled laminar flow of the metal into the mold and adequate feed to all sections of the casting. Laminar flow also minimizes the amount of gas entering the melt. Inordinate amounts of dissolved gas in the melt produce voids in castings.

Risers act as reservoirs of metal to supply a constant flow to areas of a part that otherwise may become isolated. Thin sections freeze faster than thick ones. Thus, carefully placed risers are needed to continually feed the cavity as metal contracts during cooling or else an area of the casting may not have enough metal to fill in behind the shrinking metal. The void formed as a result of this phenomenon is a casting defect known as shrinkage porosity, a major nemesis in the casting world. Ideally, risers and sprues solidify last, leading to what is referred to as "directional solidification."

Casting comparison



Sand casting involves temporary molds made from metal or wood patterns. Consequently, up-front investment for tooling is low, but per-part prices are usually higher than permanent-mold castings. Conversely, pressure-die casting has shorter cycle times which lower the per-part price, but tooling can cost up to 10 times that of permanent-mold tooling.

Permanent mold designs

Designers unfamiliar with permanent-mold processes should consult a casting house early in the design. This will help ensure that the molds will repeatably form parts to the correct tolerances. Here's a few tips for designing permanent molds that will help designers get started:

Use uniform wall thickness. Parts of the mold with the smallest cross-sectional area tend to cool and solidify first. Thick sections often act as reservoirs for molten metal, feeding material into thin sections as they solidify and shrink. However, most parts have varying cross sections and thinner sections will freeze before thicker sections. Feed paths should account for solidification from thinnest to the thickest sections.

Making the walls of the finished part all the same thickness simplifies feed-path design. Progressive solidification is easier to maintain in designs with uniform cross sections. It will also make part microstructure and mechanical properties more consistent.

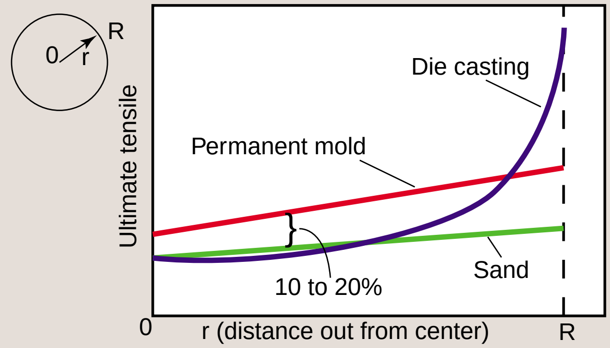
Use the proper alloys. There are aluminum alloys tailored for permanent-mold casting including 319, 356, A356, 413, and 535. In general, silicon (Si) is the most important alloying element for any aluminum casting process. Its high specific heat means it holds heat longer than aluminum. During solidification this results in a uniform freezing of the casting.

Alloys also should have a short liquid-to-solid transformation (freeze) range which helps promote strong mechanical properties. Phase diagrams illustrate the liquid-to-solid transformation. Alloys that go from liquid to solid within about 50°C are best suited for permanent-mold casting and are commonly known as eutectic alloys.

Pay attention to part details. Use fillets instead of sharp corners. Differential shrinkage at sharp corners will result in persistent shrinkage porosity, which may appear during the machining process. Ribs and gussets should be used in place of massive sections. Gradual blending of light into heavy sections is recommended. When possible, parts should be tapered for easy part ejection — 2° taper or draft is recommended for most parts. And consider coring techniques for complex shapes and even undercuts. It can eliminate secondary machining operations.

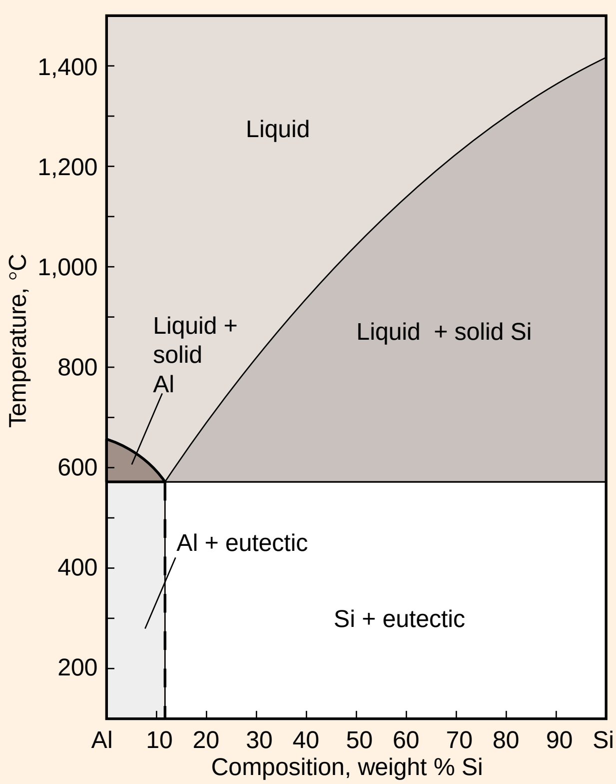
Don't forget the inserts. Forms of all shapes, sizes and materials are easily molded directly into permanent mold castings. Brass thread inserts, for example, are more durable than machined aluminum thread. Likewise, steel and stainless-steel inserts can provide the extra-hard surfaces only where needed, keeping the rest of the part as lightweight aluminum. ■

Cylinder cross section for aluminum alloy



Permanent-mold castings cool faster than sand castings, giving them a much finer, more uniform microstructure. This boosts mechanical properties by up to 20%. In comparison, pressure-die-cast parts have a much stronger skin, but weaker interior sections.

Phase diagram Al versus Si



Aluminum alloy phase diagrams are quite complicated, but for illustrative purposes, a simple two-component diagram illustrates the "freezing" or liquid-to-solid transformation range best suited for castings. An alloy with a composition of 88% Al and 12% silicon (Si), for example, has a short freeze range — on the order of 20°C. The 12% Si freezing range is the shortest on the chart and is referred to as the eutectic composition. For permanent-mold casting, eutectic alloys usually make ideal casting alloys.

An example of mold tolerances

A design guide helps uninitiated designers determine permanent-mold casting tolerances for different sized parts.

This housing for a heavy-duty portable magnetic drill weighs 7.16 lb and is highly cored to reduce the material removed during secondary machining.

Permanent-mold casting is said to easily mold this complicated double helix, 83-lb auger mechanism for a juicing machine. Secondary finishing gives the auger its bright luster.

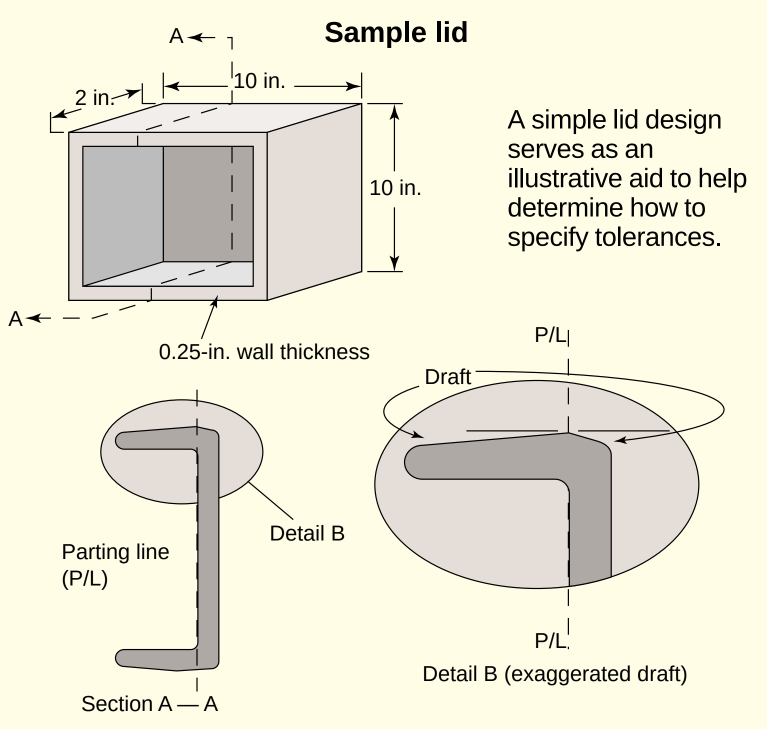
To visualize how design elements affect a casting's tolerances, consider a simple enclosure lid. For simplicity, the wall thickness is a uniform 0.25 in. and the lid consists of a 10 × 10-in. top with 2-in. walls. The casting's parting line, where the mold splits, divides the casting in half. From the table, *Designing for permanent-mold casting*, minimal linear tolerance starts at ±0.015 in. for a dimension up to 1 in. in length. For larger dimensions, the tolerance increases by ±0.002 in. for each additional inch.

Linear tolerances

Because the 2-in. dimension of the lid is split by the parting line, they can't be kept to tolerances as tight as dimensions not bisected by a parting line. The additional tolerance will be influenced by the projected area of the parting face, in our case 10 × 10 in. = 100 in.^{2} Conversely, tolerances on the lid top, which is not bisected by the parting line, can be tighter.

In our example the tolerance for the 10-in. dimension will be:

±0.015 (for the first inch of length) + 9 (± 0.002) for the additional 9 in. of length. Total tolerance for the 10-in. dimension is thus ±0.033 in.



A simple lid design serves as an illustrative aid to help determine how to specify tolerances.

Because the 2-in. dimension crosses the parting line, calculating the tolerance is slightly more involved, taking into account not only part length, but also projected parting-face surface area. With the geometry given for the lid, the projected parting-face surface area of the enclosure is equal to the area of the top, 100 in.^{2}

As before, start with the basic tolerance ±0.015 in. for the first inch of length plus ±0.002 in. for the second. This yields a starting tolerance of ±0.017 in. Now, as specified by the table, for a projected parting-face surface area of 100 in.^{2}, an additional ±0.02 in. must be added. The total wall tolerance, therefore is ±0.037 in.

Flatness

Similarly, the flatness of the lid starts with a minimum tolerance of ±0.020 in. for the first 6 in. of length and an additional ±0.002 in. for each remaining 4 in., giving an overall flatness tolerance of ±0.028 in.

Concentricity

Although not illustrated in the lid example, if two holes are to have the same center line, (i.e., be concentric), their concentricity tolerance is basically governed by the precision of the mold, shrinkage, and the diameter of the larger of the two holes. If the two concentric holes are formed by the same section of the mold (i.e., on one side of the parting line), and the larger diameter is 6 in. or less, the cast concentricity tolerance would be ±0.025. For every inch above 6 in., add ±0.003. The same approach can be used when discerning the concentricity of two holes formed on different sections of the mold. In this case, if the larger diameter is less than 10 in., the tolerance would be ±0.040. For every inch above 10 in., add ±0.003.

Machine-stock allowance

Machine-stock allowance is the amount of material needed to let the casting be machined after casting. If this allowance is not added to the overall dimensions and only the casting tolerances are used, the final part might not "clean up," or in other words, not enough metal will be left for post-casting machining.

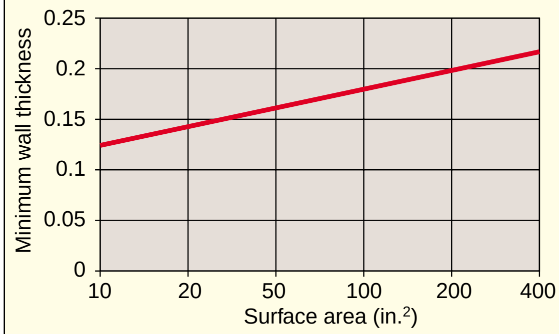
Machine-stock allowance is governed by the casting's greatest dimension. In the case of the lid, the greatest dimension is 10 in., so 1/16 in. of stock on the lip would be sufficient for face-milling or other machining processes.

Wall thickness

Wall thickness is another feature that must take into account the projected surface area of a part. As before, we use the lid example which has a wall thickness of 0.25 in. The lid starts with a minimum wall-thickness tolerance of 0.125 in. and must include a logarithmic adjustment which increases with higher surface area.

In the example, the total surface area is defined by the respective areas of the bottom as well as the four walls. This can be calculated and verified to be 180 in.^{2} From the graph, the minimal wall thickness must be no less then 0.2 in. This tells us that our 0.25-in. wall thickness should be manufacturable. These values are minimums, however, and premised on a flat plate. As part complexity increases, so should minimum wall thickness.

Minimum wall thickness as a function of surface area



Draft

All castings need draft for proper ejection from the mold. Draft is the angle or taper on a surface of a part that lets it more easily pop out of the mold. A good starting point in permanent molds is 2°, which can be reduced as the length of draw increases. It should be noted, however, that when possible, additional draft would extend mold life and makes for better, cleaner castings.

Radius

Like other casting processes, razor sharp corners are not possible with permanent-mold castings. Therefore, it is necessary to define a blending radius as a function of part wall thickness. For uniform walls, the blending radius is equal to wall thickness. The radii for two nonuniform walls, however, is the average of the two walls. ■

Designing for permanent-mold casting

	RANGE (in.)		NORMAL STANDARD	
	FROM	TO	BASE	EACH ADDITIONAL IN.
One side of parting line (basic):	0	1	±0.015	±0.002
Across parting line (Additional)	Tolerance is added as a function of projected parting face surface area. Consult foundry for details.			
	0 in.^{2}	10 in.^{2}	±0.010	
	10 in.^{2}	50 in.^{2}	±0.015	
	50 in.^{2}	100 in.^{2}	±0.020	
FLATNESS				
	0	6	±0.020	±0.002
CONCENTRICITY				
Same plane:	0	5	±0.025	±0.003
Across parting line:	0	10	±0.040	±0.003
MACHINE STOCK ALLOWANCE				
	0	12	1/16	
	12	18	3/32	
	18	24	1/8	
WALL THICKNESS				
Minimum		0.125		
**note: Minimum wall thickness increases logarithmically with surface area*				
DRAFT				
2° on all surfaces perpendicular to parting line				
2° on cored pockets and holes (draft decreases inversely with length of draw)				
**note: Additional draft extends mold life and makes better, cleaner castings*				
RADIUS				
Razor sharp corners not possible				
Recommended blending radius of *t* between two walls of thickness *t*				
For radii between two nonuniform walls, use the average wall thickness				