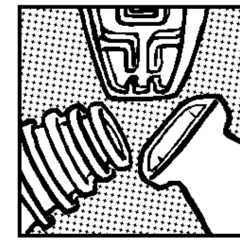
DESIGNING OPTIMUM PART SHAPES

A guide to developing the optimum product configuration for cost-effective die cast processing

Prepared for OEM designers, specifiers and purchasers by the Diecasting Development Council

Bulletin No. 2



When functional products are designed for volume production, the high-pressure die casting process is one of the prime production options considered by product engineers.

Components can be cast at high speed from a range of durable metal alloys while faithfully capturing the most intricate design details. This ability to maintain close tolerances, often eliminating *all* machining, can make the process the optimum choice for lower-volume production as well.

The introduction of new, higher-performing die casting alloys and process technology makes old design assumptions about the limitations of the process obsolete. Dimensional specifications, draft angles, as-cast flatness, and porosity reduction can be achieved to levels unheard of just a few years ago.

A Systematic Design Approach

To configure a product design to maximize performance, economy, and ease of manufacturing by die casting, a systematic approach is needed.

The objective of good product design is to develop the optimum configuration consistent with product function, material, and manufacturing processing. With the increasing emphasis on achieving the benefits of designing for manufacturability, the second and third elements of this objective have taken on added importance. Three tasks are essential to reach the desired goal through die casting:

- Defining the product function independent of existing or traditional forms.
- Developing a configuration that can be readily produced by die casting and meet product objectives in the selected alloy.
- Utilizing design features that are consistent with the die casting process and capitalizing on its unique characteristics.

Fig. 1. This wheel design was developed for die casting as a cost-effective alternative to the conventional steel rim and wire spoke design.

1. Defining Product Function

Creative design should begin with a clear statement that precisely defines the product functions to be performed, independent of the traditional form. The traditional form of a product is usually governed more by the constraints of the existing material and manufacturing process than by the functions it performs. A clear statement of product functions will overcome the tendency to link functions with the forms traditionally employed and eliminate a common barrier to creative design.

Case in Point: The Wheel

This point is illustrated by the development of the wheel. Old-style wooden wheels employed heavy spokes to transmit loads from the rim to the hub. Steel wheels use a stamped, developed disk for heavy-duty applications and thin, prestressed spokes for light duty. The wheel shown here, designed to be made by die casting for light duty applications, utilized a structure compatible with the die casting process. Heavy spokes are impractical for die casting, a thin disc of sufficient strength is not material-efficient, and wire-like spokes are impossible to die cast.

Radial and lateral loads in the die cast design are transmitted from the outer rim to the hub by six broad, thin spokes oriented axially to transmit lateral loads from the outer rim to the hub. The outer rim is reinforced against both radial and lateral loads by six shorter intermediate spokes supported by an intermediate rim. The intermediate rim also distributes lateral loads to adjacent spokes. This design can be readily die cast using aluminum or magnesium alloys for applications such as wheelchairs and bicycles. It can also be used as an inertia wheel for stationary exercise bicycles by converting the outer rim to a more massive, solid section and selecting a zinc alloy.

The die cast wheelchair wheel shown in the photo incorporates four bosses with tapped holes located near the outer rim to support the tubular rim used for hand propulsion by the occupant. The broad spokes and open design are easy to clean, an important benefit in clinical applications. In this case a clear understanding of function enabled the product designer and die caster to get together and "reinvent the wheel."

2. Developing the Configuration

After product function has been defined, a configuration compatible with the die casting process and the selected alloy must be developed. Alloy selection is based primarily on the required mechanical, physical and chemical properties. When more than one die casting alloy is feasible, relative economics generally prevails.

A product configuration optimized for die casting will:

- Fill completely with metal.
- Solidify quickly and without defects.
- Eject readily from the die.

These results can best be achieved by applying six principles when designing component walls and sections and establishing tolerances.

Six Developmental Principles

1. There are no hard and fast rules governing maximum and minimum limits for wall thicknesses. They should be as consistent as possible throughout the component and, where variations are required, transitions should be provided to avoid abrupt changes. Die casters who use high-technology equipment and techniques routinely produce castings with maximum and minimum wall thicknesses and with variations that were impossible until recently. This capability should be utilized only as necessary to achieve performance or economic advantages. Uniform wall thicknesses are otherwise preferred.

2. Intersections of features, such as walls, ribs and gussets, should blend with transition sections and generous radii. This practice promotes metal flow and structural integrity and rarely creates a conflict between casting requirements and product integrity.

3. Draft angles may be minimized where metal content is critical, such as thin sections oriented parallel to die draw. Casting to zero draft may be specified in some cases to eliminate finish machining operations. These capabilities may be utilized as necessary to gain an economic advantage or to reduce weight. In all other cases standard draft, per the NADCA Product Standards Manual, should be specified to facilitate ejection from the die and reduce die maintenance.

4. Sharp exterior corners can be specified on appearance surfaces when crisp styling features are desired. Otherwise, sharp corners should be broken with radii or chamfers to reduce die maintenance.

5. Undercuts should be avoided whenever possible, because they require machining operations or additional die members, such as retractable core slides. When core slides are used, the design should allow them to be located in the die parting plane.

6. Dimensions with critical tolerances should relate to only one die member, where possible. For example, axial concentricity between bores C and D can be held closer with the design shown in the first diagram than in the second. The core slides that form the bores in 2a are both located in the ejector die half. In 2b, one is in the ejector half and the other in the cover half, requiring additional tolerance because of the variations in die alignment.

Fig. 2a

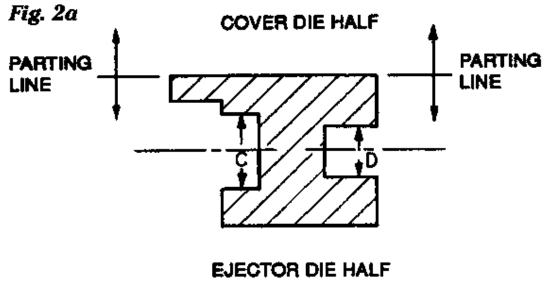


Fig. 2b

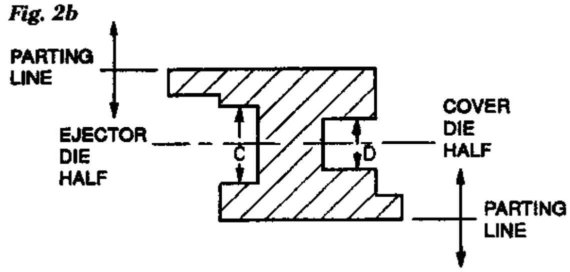


Fig. 2. *The alignment of bore C to bore D can be held to closer tolerance in Fig. 2a than in Fig. 2b. Both bores are in the ejector die half in Fig. 2a; in Fig. 2b, bore C is in the ejector die half and bore D in the cover die half.*

3. Utilizing Features to Capitalize on the Process

Many features can be readily die cast when proper detail dimensions are specified. The configurations and dimensions recommended in this section tend to: fill consistently; reduce the tendency for defects such as sink marks and porosity; minimize die wear; and eject easily.

Fillets and corners

Fillets, which connect interior surfaces of a component, are molded at the juncture of external die surfaces. Properly sized radii enhance structural integrity by reducing stress concentration, and promote good metal flow with reduced erosion in the die. Corners generated by the junction of exterior surfaces of a component are molded at the juncture of internal die surfaces. Properly sized radii relieve stress concentrations in the die and ensure that molten metal fills corners proper-

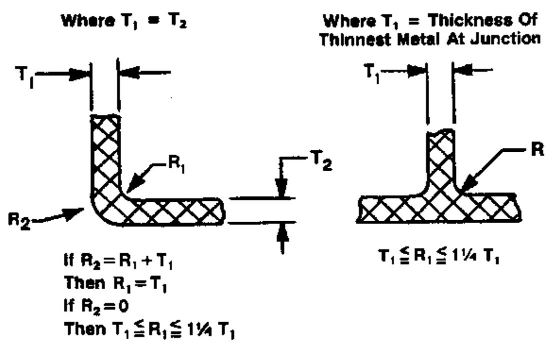


Fig. 3. ***Recommended dimensions for fillets:*** *R_1 too large causes heavy masses, not conducive to sound metal in casting. R_1 too small is difficult to maintain in the die. $R_1 = 0$ is difficult to maintain in die, causes weak casting.*

ly. Figure 3 illustrates sound principles for fillet and corner design for die castings.

Ribs

Ribs are employed for reinforcement more than any other feature. Die casting technology currently allows deeper, thinner ribs than were previously feasible. Figure 4 illustrates principles for configuring ribs and interfacing them with other features.

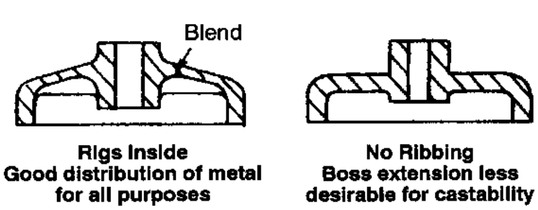


Fig. 4. ***Recommended configurations for ribs***

Reducing heavy masses

Heavy masses are usually redesigned with thinner walls and rib reinforcements. Sometimes extensive redesign is possible, to preserve essential features and revise nonessential features. Figure 5 illustrates conditions where heavy masses were redesigned and features modified.

Die simplification

Some features, such as undercuts, bosses and holes, require core slides because their features are not oriented in the direction of die draw. Slides increase the costs of fabricating

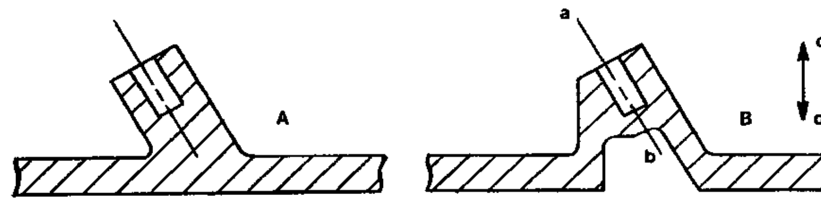


Fig. 5. ***Reducing a heavy mass under a boss:*** *The heavy mass of metal trapped in the design of the boss at A may be reduced by using a metal-saver-core as shown at B. With design B, the direction of die pull may be either in the direction a-b or c-d.*

and maintaining the die and increase the casting cycle time. They also tend to cause flash on exterior surfaces. When removal is necessary, additional costs are incurred.

Punched holes

In thin-wall castings it is sometimes advantageous to punch holes in features to eliminate the need for core slides that would otherwise increase die cost and wear. Punching can also

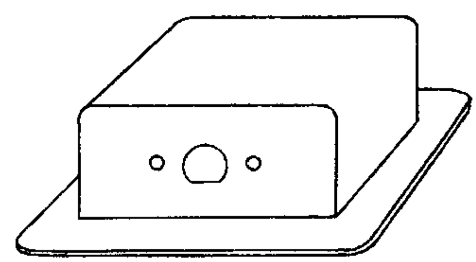


Fig. 6. The holes in the side walls of a thin-wall die cast box can often be punched after die casting more economically than forming with a core slide.

save additional cleaning operations. Figure 6 shows a thin-wall box with holes oriented in a way that would require core slides. Punching is often a cost-effective option in this type of application.

Die parting

The die parting plane location may be important to the casting because of the line left on the casting where the die halves meet. The casting must be trimmed along this line, and the trim die must be configured to it and maintained. Simplification of the parting line configuration will reduce the cost of manufacturing and maintaining the trim die. In some cases, a simplified parting line may negate the need for clean-up operations on exterior surfaces. Minor design modifications can often simplify trimming operations and eliminate the need for clean-up.

Eliminating undercuts beneath bosses

Undercuts beneath bosses form features that lock the casting onto the die and prohibit ejection. Where the features cannot be eliminated, machining operations or core slides are

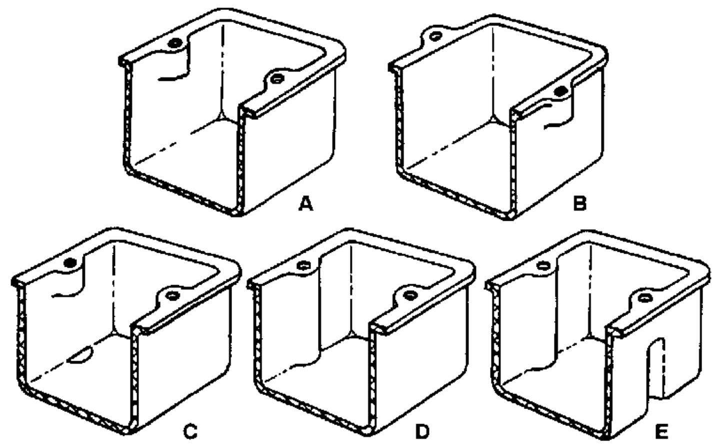


Fig. 7. Four alternatives for eliminating undercuts at bosses. *The housing is shown as desired at A, but the bosses create undercuts. Four options are illustrated for eliminating the undercuts.*

B. The boss is relocated outside the housing.

C. The boss is cored by breaking through the bottom wall of the housing.

D. The boss is extended to the bottom of the housing.

E. The exterior wall of the housing is cored.

required as noted above. In some cases the location of undercuts prohibits die casting. Figure 7 shows four design alternatives that eliminate an undercut formed by an interior boss without requiring core slides.

Draft requirements

Draft is highly desirable on surfaces parallel to the direction of die draw because it facilitates ejection by allowing the casting to release easily from the die surfaces. Draft may be minimized or eliminated on a limited basis to gain economic advantages; otherwise, NADCA Product Standards recommendations for minimum draft should be specified. The NADCA recommended standard tolerance draft can be approximated by the formula:

$$D = \sqrt{L} / C$$

Where: D = draft in inches
L = depth or height of feature from the parting line
C = a constant, based on the type of feature and the alloy

The values of C for the features shown in Figure 8 are:

Alloy Group	Inside Surface	Outside Surface	Hole, Total
Zinc and ZA	50	100	34
Magnesium	35	70	24
Aluminum	30	60	20

Note that twice as much draft is recommended for inside surfaces as for outside surfaces. This provision is made because, as the alloy solidifies, it shrinks onto the die features that form inside surfaces (usually located in the ejector half) and away from features that form outside surfaces (usually located in the cover half).

The formula indicates that draft, expressed as an angle, decreases as the depth of the feature increases. For example, consider an aluminum alloy inside surface, for which $C = 30$.

Depth, in. (mm)	Draft, in. (mm)	Draft, Degrees
0.1 (2.5)	0.010 (0.25)	6.0
1.0 (25)	0.033 (0.84)	1.9
5.0 (127)	0.075 (1.89)	0.85

It is not common practice to compute the draft for each feature. Draft is usually specified by a general note with exceptions called out for individual features. The formula is useful for establishing general draft requirements and identifying exceptions. For example, the table above indicates that an aluminum die casting with most features at least 1.0 inch deep can be covered with a general note indicating 2° minimum draft on inside surfaces

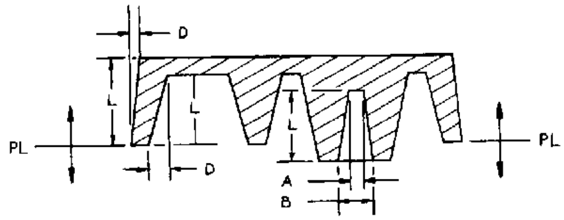


Fig. 8. Draft dimensions defined for interior and exterior surfaces and for holes (draft is exaggerated for purposes of illustration).

and 1° minimum on outside (based on outside surfaces requiring half as much).

In designing for cost-effective die casting production, the product engineer should consult early with a die caster knowledgeable in today's advanced die casting technology.

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