Some Pointers for Designing Die Castings

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Die castings offer exceptional design freedom while still getting great mechanical properties in a product. However, some features can cause quality problems and others can add unnecessarily to the cost of the casting. This article gives some pointers on how maximize the value of the casting.

Flat Is Good

Before starting the design, the requirement's features should be studied and the designer should develop an idea of what the general size and shape of the casting will be. Figure 1 shows some hypothetical requirements for a casting that must encase some mechanism, hold a fluid in and keep anything else in the environment out.

The casting might look like that shown in Figure 2.

The requirement's features, as shown in the left illustration of Figure 3, should be rotated to a position that results in the smallest height, as shown in the right illustration of Figure 3 before starting the casting design. If a good design is not possible at that rotation, then the features must be rotated to where a good design is possible. Some die cost and casting machine operating factors are generally improved with reduced cavity depth. The "flat is good" rule is not a hard and fast requirement, but it is a good starting point.

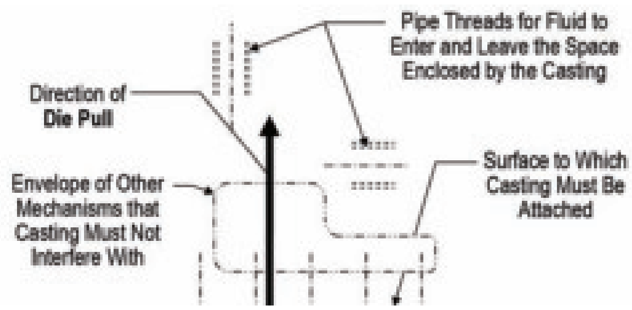

Figure 1 – A casting must be designed to contain some fluid around the mechanism and keep dirt and water out.

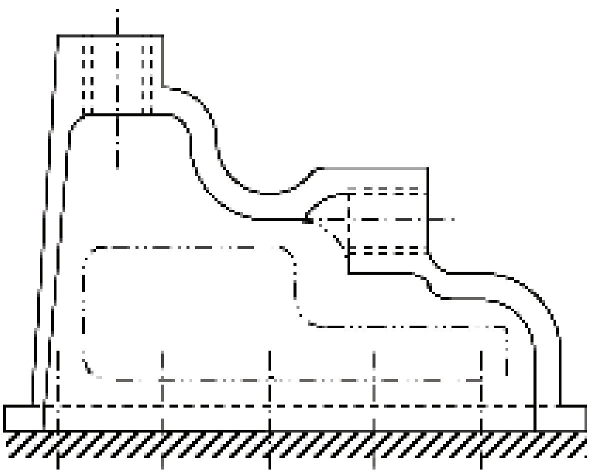

Figure 2 – The casting for the requirements shown in Figure 1 might look as shown here. The features would be designed to the die pull arrow.

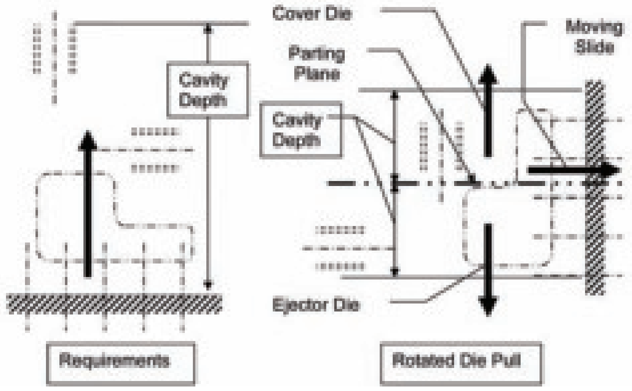

Figure 3 – When the requirement's features create a deep cavity, as shown in the left illustration, it is sometimes beneficial to rotate the features to reduce the depth of the cavity(ies). It is sometimes even worth adding a moving slide, as shown in the right illustration, to reduce the cavity depth.

Changing Wall Thickness

One guideline that is often parroted is that the wall thickness should be constant. Actually, that rule is not exactly right. The wall thicknesses should be the thicknesses that best meet the part function. The difference in wall thickness from one area to another is not what induces casting problems; it is a sudden change in thickness that can make the casting difficult to cast.

A casting wall should change thickness at a rate of at least one to five, as shown in the left illustration of Figure 4. If a sharp corner with the possibility of some flash sticking up is allowable, or if the cost of removing the flash is acceptable, a sudden change in casting thickness, as shown in the right illustration of Figure 4, can often be accommodated. The "insert seam" in the die cavity provides for maintaining the severe temperature gradient in the die required to properly solidify the different thicknesses.

Figure 4 – Casting wall thicknesses should change gradually, as shown in the left illustration, unless an insert seam line is acceptable on the casting, as shown in the right illustration.

Wall Thickness

Various recommendations are available, and some companies even have standards for minimum casting wall thickness. No material property limits the thinness of a casting wall. As the wall is made thinner, the metal injection power required of the die casting machine increases, and usually the die clamping tonnage increases also. Die castings have been made in all alloys at 0.5 mm thickness, and some have been made at 0.3 mm. A recent study commissioned by the USCAR organization showed that castings as big as a meter squared could be made 1.0 mm thick. It was concluded in that study that the die casting industrial culture, not material properties, negate the feasibility of such castings.

The limitation on thinness is a particular casting supplier's equipment and foundry practice. When a casting looks a lot like another but has a thinner wall, the casting machine power requirement increases significantly, and the required foundry acumen can take a quantum leap.

The casting should be designed with the minimum wall thicknesses required for the product function, and then increased as required by the die caster for his capability.

Dimensioning Datums

Unlike a machined part, a die casting is not created by controlling a cutter through a series of x, y, z coordinates from some known coordinate system (e.g. the classical 3-2-1 locating system). It is made within two or more blocks of steel, as shown in Figure 5, that have been carved into the shape of the desired casting using such a coordinate system. The difference is subtle, but both real and important. The base of the coordinate system (i.e. the 3-2-1 locating points) used for creating the dies might not — and, in fact, usually doesn't — exist on the casting. Also, the two or more blocks of the die move in respect to each other from casting-to-casting. The relationship between features formed entirely in one member of the die have a completely different pattern and magnitude of variation from casting-to-casting than between features formed in two different die members. The nature and magnitude of dimensional variation between features formed by different die members depend on the direction of the dimension in respect to the die pull and the locking strategy of moving slides.

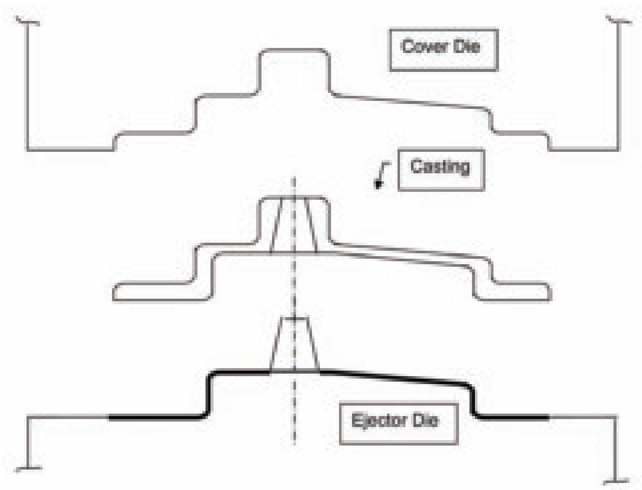

***Figure 5** – A die casting is made from two blocks that have had the shape of the casting carved into them.*

The types of variation and magnitudes typical of the industry are given in the *NADCA Product Specification Standards for Die Castings*. The physical phenomena and the mathematics between the magnitude of variation and the relevant processing variables are described in the NADCA course and textbook, *Dimensional Repeatability*.

The casting must have a 3-2-1 datum system for each die member (i.e. the cover die and the ejector die in Figure 5) and must have tolerance dimensions relating the datum systems to each other as shown (conceptually) in Figure 6. The datum reference points must exist on both the casting and the die cavity. GD&T methods exist for achieving such dimensioning systems.

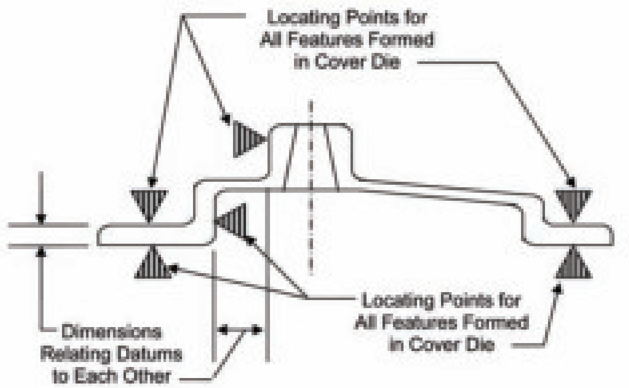

***Figure 6** – The casting must have a datum system for each die member, and the datum systems must be related to each other with dimensions and tolerances.*

A Casting as a Composite

The material in a die casting is not a monolithic structure as in wrought materials such as sheet steel, sheet aluminum or tool steels. The casting consists of a dense, fine-grained skin with a coarse-grained and porous core, as depicted in Figure 7. There will be porosity. The design of the product, the design of the die and the control of the casting process act as a single system to ensure a reasonable minimum porosity and to position the remaining porosity where it will not detract from the function of the casting.

The composite structure is the result of solidification progressing from the cold die surface inward toward the

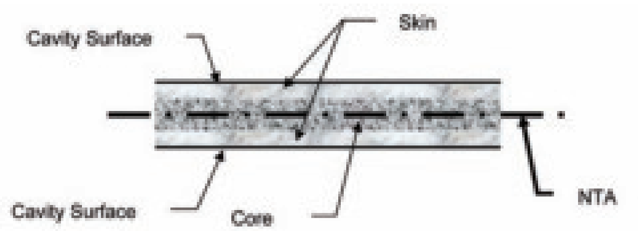

***Figure 7** – A die casting has a dense, fine-grained skin and a coarse-grained and porous core.*

center. Solidification is rapid at the cold die surface and slows as it advances. The advancing solidification fronts meet at the neutral thermal axis (NTA). Since it is a closed system once the skin forms, the natural shrinkage of the metal — as it changes from liquid to solid — results in voids (i.e. porosity) in the material composite system. Capillary action pulls liquid to the solid surface, causing a general — but not perfect — migration of the pores toward the NTA. The porosity tends to cluster around the last place to solidify, which is at the NTA. The slower the solidification, the more perfectly the porosity will reside at the last place to solidify.

For most die castings, it is desirable to have the NTA midway between the outer surfaces of the casting wall, but this is not always true and does not always happen that way, even when it should for the function of the casting. Figure 8 shows how casting shape can cause the NTA to not be in the middle of the wall and can be on the casting surface or even outside of the casting. When the NTA is at the surface or outside the casting, the porosity will be on the casting surface.

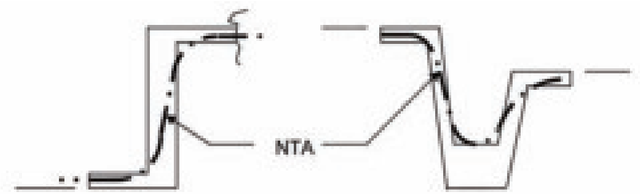

Figure 8 – The neutral thermal axis is not always in the center of the wall thickness.

The position of the NTA can be strongly influenced by the local temperatures in the adjacent die steels.

The illustration in Figure 7 implies that the casting solidification pattern results in the solidifying fronts all meeting at the NTA at the same time everywhere throughout the casting. That might, or might not, happen. For example, if both die halves were hotter on the left end of the casting in the figure and colder on the right end, the casting would solidify first on the right end. The solidifying fronts would meet first at the right end and the meeting would move progressively to the left. The right end of the casting would be denser with less porosity than the left end.

The ramifications of the significance of the NTA and how to manage and specify it are beyond the scope of this article. The NTA can be manipulated by design, but practical limits exist that cannot be exceeded. The product designer should learn how casting features, die features and process controls interact to affect the NTA and then think about where porosity can be detrimental to the function of the casting and how to design the casting so the shape of the casting will naturally move the porosity away from where it would hurt the function of the casting. The product designer might even specify the location of the NTA and include it in the product CAD data. But, if the die caster does not design and control the die according to the NTA strategy of the casting design, the desired performance will not be achieved.

Casting Features, Die Features and Process Controls Interact as a Single System

Equally important is to identify regions within the casting where large amounts of porosity will not hurt the function of the casting. Such areas could be outlined with an envelope surface (within the casting) and the region within the envelope specified to be "exempt" of X-ray porosity specification.

The NTA can have holes. These holes are places that are forced (by die cooling design and control) to solidify significantly before the surrounding casting and hence are nearly porosity free. Such "holes" cannot be large. The limit on the size of a hole in the NTA is probably 10 to 20 metal thicknesses in diameter. But even with the size restriction, a "hole" can be significant and might justify being specified on occasion.

Because of the composite nature of the cast structure, standard test specimens and procedures are usually too small to adequately test a casting's material. The result is that most castings perform much better and much more consistently than the test data from specimens cut from the castings would lead one to expect.

Perspective

The successful die casting is one that has been designed, deliberately or by chance, to be within the capability of the die caster. There is no "ideal" casting design. There is, however, an "ideal" casting design/die design process control system. That system can be primitive or sophisticated and still be ideal if it works. When a casting is designed out of context of the capabilities of the die caster, one is asking for trouble. If the casting design needs a sophisticated die caster, but is placed with an unsophisticated die caster, it will fail. If the design only needs a primitive die caster, and it is placed with a sophisticated die caster, it will be too expensive.

About the Author

Edmund Herman, currently president of his own consulting firm Creative Concepts Co. Inc., has been in the industry for 38 years and has been involved with NADCA/SDCE (Society of Die Casting Engineers) almost as long. Herman has been recognized by the association with distinguished lifetime membership and most recently was awarded the Herman H. Doehler Award for his work for the advancement of the die casting industry. Herman is a NADCA-certified instructor and has been teaching educational courses since 1972, some of which he developed. He can be contacted via e-mail at edmundaherman@comcast.net.