Investment Casting Design Parameters

The following guidelines and technical information outline what an investment casting is capable of offering. It will cover dimensional and structural topics. The integrity of a part, both dimensional and structural is proportional to the cost of the finished part. This is true of investment castings, as well as fabricated and machined parts. Investment castings are designed to minimize the cost of producing close tolerance parts.

Maintaining close dimensional tolerance in an investment casting is affected by many factors. Most of these factors can be controlled by the foundry, although minor "lot to lot" variations will occur. The tolerance bands provided for investment castings are determined by these variations in the process.

Machining can achieve closer tolerances than available in an investment casting. A review of the design will often permit expansion of some tolerances, undercuts, blind holes, etc. to allow the higher production yields and lower piece costs possible with investment castings. If closer than cast tolerances are necessary, the machining required on an investment casting will still be substantially less than on conventional cast or fabricated pieces. An added benefit of an investment casting is the ability to add radii and other detail that would be more expensive with traditional manufacturing processes.

VARIABLES

Casting size and shape determines the tolerance required to allow for process variables. Many process factors affect investment casting tolerances, such as:

1. wax temperature
2. wax die temperature
3. the amount of pressure applied to inject wax into a die
4. firing temperature of the ceramic shell
5. ceramic mold refractory composition
6. cooling rate of the metal
7. lot to lot variation of raw materials

STANDARD LINEAR TOLERANCES

As a general rule normal linear tolerance on an investment casting can be +/- .005 of an inch per inch or +/- .125 of a mm per 25mm.
The following table gives a partial listing of dimensions and tolerances.

LINEAR TOLERANCE

Dimension	**Inches** (English)	**Dimension** (Metric)	**MM** (Metric)
0" up to 1"	+/- .005	0 up to 25.02	+/- .13
1" + up to 2"	+/- .010	25.02 + up to 50	+/- .25
2" + up to 3"	+/- .015	50.02 + up to 75	+/- .38
3" + up to 4"	+/- .020	75.02 + up to 100	+/- .50
4"+ up to 5"	+/- .025	100.02 + up to 125	+/- .63
5" + up to 6"	+/- .030	125.02 + up to 150	+/- .75
6" + up to 7"	+/- .035	150.02 + up to 175	+/- .88
7" + up to 8"	+/- .040	175.02 + up to 200	+/- 1.0
8" + up to 9"	+/- .045	200.02 + up to 225	+/- 1.13
each inch after	+/- .005	each 25 MM after	+/- .125

FLATNESS

Flatness and straightness are so closely related that confusion may arise unless the foundry and purchaser clarify the definitions before production. Flatness tolerance is a tolerance zone defined by two parallel planes within which the surface must lie. In measuring *(see Fig. 1)*, the parallel planes must be the minimum distance apart.

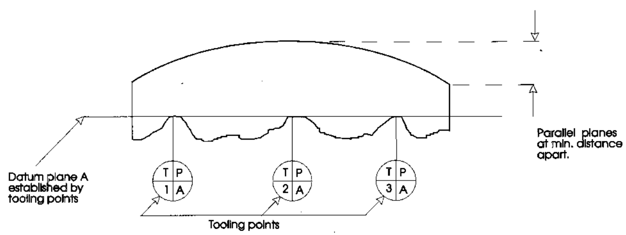

Figure 1

Degree of flatness in an investment casting is almost always determined by the volumetric shrinkage of the wax pattern and then by the metal during cooling. Shrinkage usually occurs in the center of a mass, this shrinkage is called "sink". Sink can be controlled by specialized techniques, but it will always occur to some extent. General flatness tolerances cannot be quoted because they vary with the configuration of the part and alloy used. The following is a rough guide derived from data collected from standard test procedures.

Section Thickness	Volume of Section	Possible Sink per Face of Casting
Inches	In^3	
.25	.5	not significant
.5	1	.005
1	2	.012
2	8	.014
Millimeters	mm^3	
6	13	not significant
12	25	.13
25	50	.3
50	200	.36

Allowable sink is in addition to the basic tolerance. For example (see figure 2), on a block 1" +/- .005 thick (2.5mm +/- .13mm) the allowable sink may affect the tolerance of the part an additional .008":

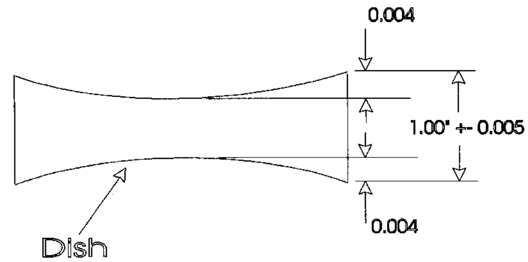

Figure 2

The method of measuring flatness should be specified by the purchaser. It may vary from a simple surface plate and feeler gage to full layout with equalization and dial indicators.

STRAIGHTNESS

Straightness tolerance is a tolerance zone within which an axis or the considered element must lie. Thus, to correctly measure axial straightness of a shaft, bar, or plate, *(see Fig.3 & 4)* the tolerance zone within which the axis or axial plane lies must also be measured.

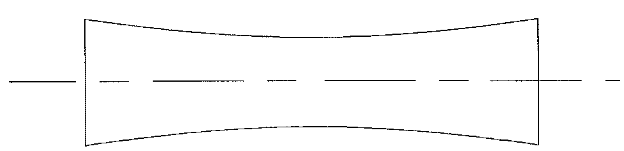

Figure 3

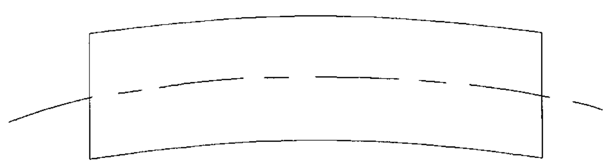

Figure 4

Straightness may be a real problem with certain types of castings. A relatively thin, short part may bend while a long, heavy part may not. Experience tells us that a given design may bend, but it cannot indicate to what extent. Ribs and gussets will inhibit warpage, but will also hinder mechanical straightening of whatever warpage did occur.

PARALLELISM

Parallelism is the condition of a surface equidistant at all points from a datum plane or an axis equidistant along its length to a datum axis.

Parallelism is difficult to control in the as cast condition and may require a straightening operation. Parallelism is a feature that is a function of the complexity of the part. As the part is being designed, consult your foundry for tolerances.

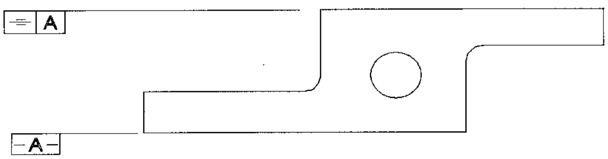

Figure 5

For example, casting parts with parallel prongs supported at only one end *(see Fig. 5)* and yoke castings *(see Fig. 6a)* are very specialized problems which should be discussed fully with the foundry before production.

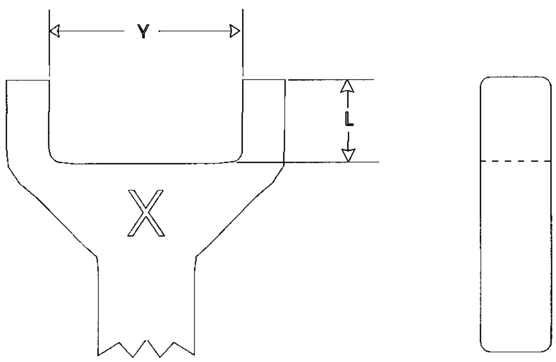

Figure 6a

In Figure 6a, point X is the thickest section, it is the ideal gate point. It is also where the greatest volumetric shrinkage will occur. Dimension Y, however, will be restrained by the rigid mass of refractory used to produce the mold. Parallelism is therefore difficult to maintain. It can be improved by control techniques and sizing.

This condition will also affect any through holes usually found in yokes *(see Fig.6b)*. When specified, such holes should carry considerable finish stock for machining if they are to be finished truly concentric.

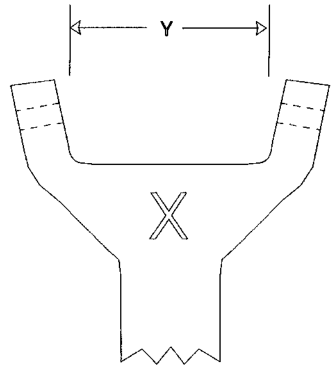

Figure 6b

ROUNDNESS

Roundness tolerance specifies a tolerance zone bounded by two concentric circles within which each circular element of the surface must lie. It is the total indicator reading (TIR) when the part is rotated 360º, or calculated by taking half the difference between the maximum and minimum condition. The latter is usually preferred because it is quicker to determine. The actual inspection method, however, should be specified by the purchaser.

CONCENTRICITY

Concentricity is a condition in which two or more features (cylinders, cones, spheres, hexagon, etc.) in any combination have a common axis. For example, any two cylindrical surfaces sharing a common point or axis as their center are concentric. Any dimensional difference in the location of one center with another is the extent of eccentricity.

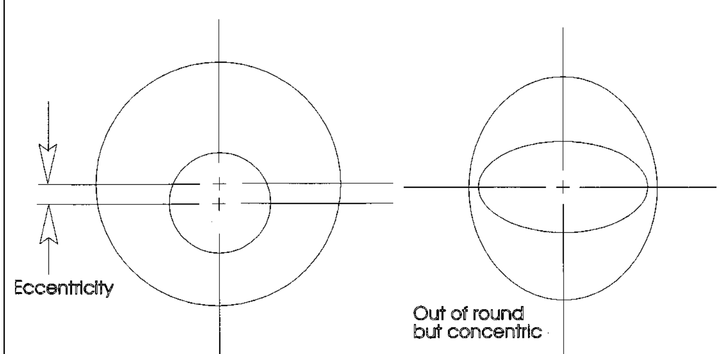

Figure 7

Figure 7 shows that out of roundness in either diameter does not affect concentricity because concentricity is determined by the centers or axis.

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CONCENTRICITY *(Continued)*
Out of roundness is variance from a true circle. Straightness does influence concentricity if the casting has a shaft or tube feature.

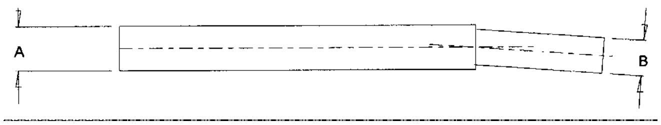

Figure 8

In Figure 8, diameters A and B may be true circles, but the out of straightness affects concentricity.

When the length of a bar, a casting, or tube is not more than 2 times its component diameters, the diameters will be concentric within .005" per 1" of separation *(see Fig. 9 below).*

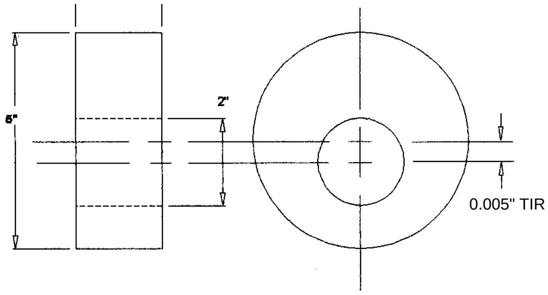

Figure 9

5"OD x 2"ID x 2" long
The 5"OD x 2"ID will be concentric within .015" TIR
5"OD - 2"ID = 3" separation.

When the length is more than two times the diameters, out of straightness should be added to eccentricity *(see Fig. 10 below).*

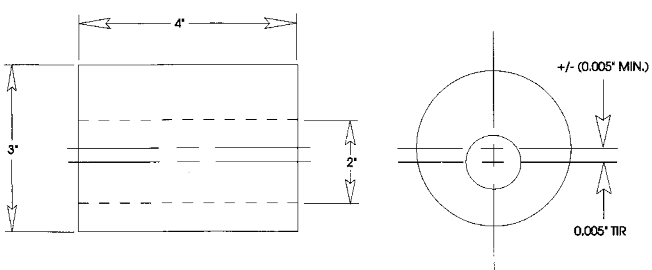

Figure 10

3"OD x 2"ID x 4" long
3"OD x 2"ID will be concentric within .005" TIR
3"OD-2"ID = 1" separation.

ANGULARITY

Angularity is the condition of a surface, axis, or center plane which is at a specified angle (other than 90 degrees) from a datum plane or axis *(see Fig. 11 below).* As a designer you should be aware the angularity of a component part to be maintained may require the part to be mechanically straightened or the die reworked. In heavy sections, the die may need to be reworked, and in thin sections, the casting may be straightened to achieve angularity tolerances. Angular tolerance depends on the configuration forming the angle. Sketch "A" cannot be sized, but in certain cases after sufficient data review, the die can be reworked to bring the part closer to optimum. Sketches "B" and "C" represent castings that can be reworked to +/- 1 degree, depending on the alloy and its condition.

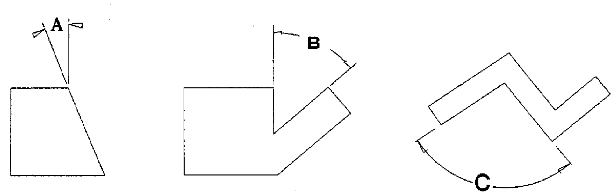

Figure 11

POSITIONING

Position tolerance is dependent on the parent casting configuration. A casting that is less symmetrical in confirguration yields greater deviation in position tolerancing. A part that is symmetrical, with consistent cross section, will yield the best positioning tolerances. Features such as holes, pockets or slots that can restrict the casting's ability to shrink properly will effect the position features around the restricting feature. A linear dimension may be affected approximately 5% because of a restricting feature. Features that have heavy sections near, can be effected by the volumetric shrinkage of the heavy section. This will pull or distort the feature in the direction of the heavy feature. It is difficult to predict the exact amount of the pull or distortion, and the foundry may wish to rework tooling to minimize its effect and to improve the position tolerance.

In general, a consistent cross section with gradual changes from heavy to light sections that leaves the heavy section open for gating purposes will yield the best over all casting and position tolerance.

HOLE TOLERANCE

Standard linear tolerances will apply*(see page 1)*. But a cast hole's roundness is affected by the surrounding metal. If an uneven mass is adjacent, the hole will be pulled out of round. If the surrounding metal is symmetrical, holes up to 0.5" (1.3cm) diameter can be held to +/-0.005" (0.013cm).

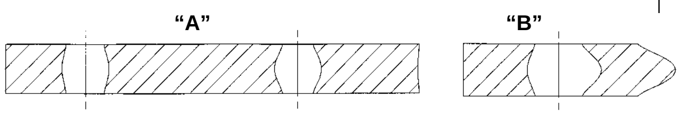

Figure 12

The longer the hole or the more mass in the section around it, the more pronounced the pull effect. "A" *(see Fig. 12)* shows the effect of hole shrinkage concavity which will be present to some extent in all castings. The top and bottom openings will be approximate dimensions, while the center will be a larger diameter. Thru holes that require clearance can be held to fairly close tolerances if the large diameter (bow) in the center is ignored. If the sidewalls of the hole are used as bearing surfaces, simple reaming should be sufficient. "B" shows how a heavier section close to the hole distorts the shrinkage pattern. The hole diameter is distorted by the additional shrinkage of the heavier section. The figure graphically shows the pattern of distortion present to a greater or lesser degree in every casting with heavier mass affecting shrinkage.

CURVED HOLES

Since curved holes are formed by either soluble wax or preformed ceramic cores, normal tolerance requirements tend to double *(see Fig.13)*. Multiply the tolerance on all dimensions controlling such a feature by two. Since such holes cannot be sized, a diameter tolerance of an additional +/- 0.005" per inch may be required.

INTERNAL RADII, FILLETS

Internal radii and fillets improve the strength and integrity of the casting. Shrinkage and cracking are reduced. Internal radii and fillets require the widest tolerance possible. They are difficult to control and can receive approximate checks by radius gages.

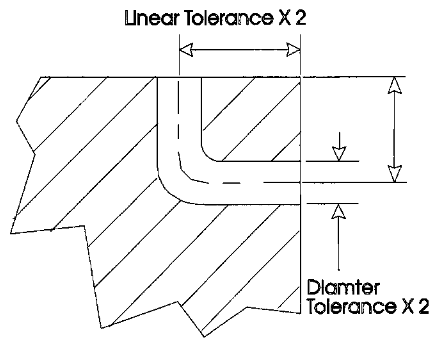

Figure 13

CONTOURS, RADII AND CAMS

When dimensioning a casting radii, it must be remembered that volumetric shrinkage occurs during cooling which affects external radii and contours. Most of the volumetric shrinkage will occur in the center of the radius.

In regards to a flat casting, the design considerations for concavity are discussed in the *Flatness section, page 2*. The same concavity also affects castings that have contour, but with more dramatic results. In this case, it is advised that when dimensioning your drawing that a basic dimension along with a profile tolerance be used .

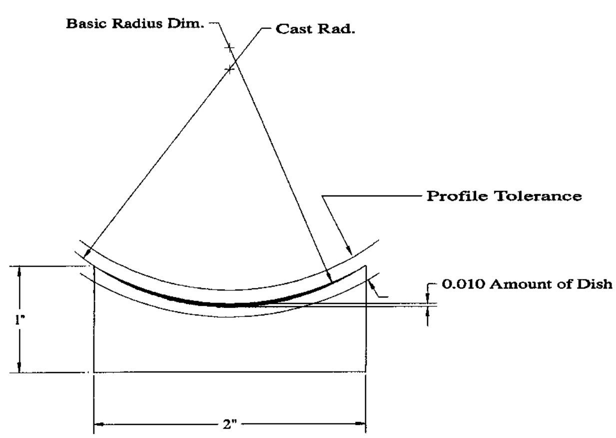

Figure 14

In a concave radius, the greatest shrinkage occurs in the center and outer extremities. This tends to decrease the radius. When dimensioning a drawing of a concave radius *(see Fig.14)*, a basic

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CONTOURS, RADII, AND CAMS *(Continued)*
dimension for the radius should be used with a profile tolerance. The fit to a mating configuration is then controlled by using a tolerance band on the radius.

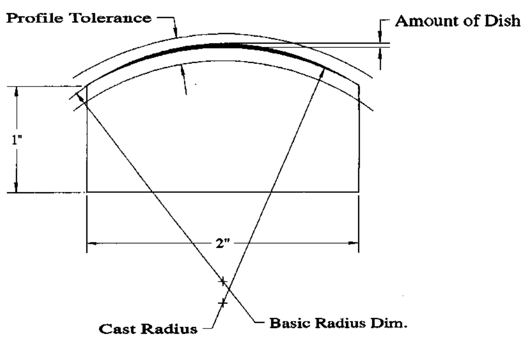

Figure 15

In a convex radius, the greatest shrinkage also occurs in the center. This tends to increase the cast radius *(see Fig.15)*. The drawing should be dimensioned accordingly. When dimensioning a drawing of a concave or convex radius, a basic dimension for the radius should be used with a profile tolerance.

SURFACE TEXTURE

"Surface texture includes roughness, waviness, lay, and flaws" as defined in ASNI-ASME B 46.1-1985. Values stated are in Ra (Roughness average), as measured by a profilometer.
Typical cast finishes of ferrous alloys range from 125 to 150 Ra. Aluminum castings will range from 180 to 200 Ra.

All lay is multi-directional except in ground areas. Secondary operations will improve surface texture, giving results comparable to the equivalent wrought alloy.

PERPENDICULARITY

Perpendicularity is the condition of a surface, axis, or line which is 90 degrees from a datum plane or datum axis. When specifying perpendicularity, use the longest plane for reference, establishing the datum plane with three tooling points. The shortest surface will be perpendicular to the longest within .005" per inch of length of the shortest surface.

In Figure 16 *(see below)*, for example, surface B will be perpendicular to surface A within 0.005" per inch (0.13cm per cm) of length of surface B.

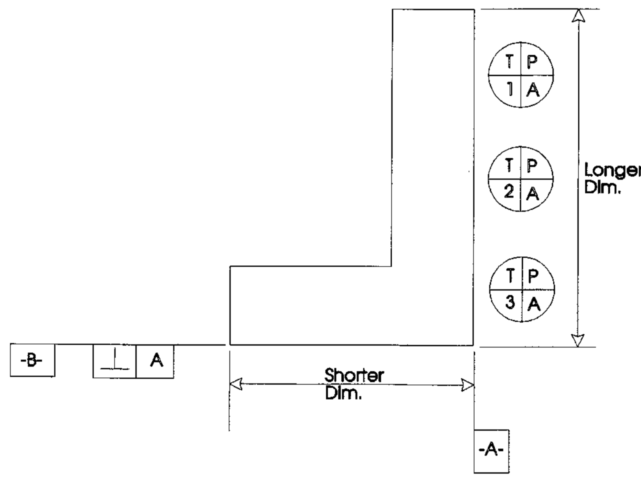

Figure 16

EXAMPLE:
Length of B = 3"
0.005" x 3" = 0.015"

THEREFORE:
Surface B should be perpendicular to surface A within 0.015 TIR.

Some improvement on a tolerance can be made by mechanical straightening.

CASTING INTEGRITY

The integrity of a casting may vary depending on the customer requirements of the part. In the interest of producing a casting with the greatest detail possible, thus reducing overall cost, casting integrity can be sacrificed. These issues should always be thoroughly discussed with the foundry. The following guidelines will help to insure the soundest casting possible.

Directional Solidification

After a casting is poured the molten metal will reduce in volume, changing to a solid. This requires that the molten metal has a path to feed the area of decreasing volume. Directional Solidification is a castings ability to successfully feed these solidifying areas. As the casting design moves away from good directional solidification, problems will occur. A casting design with a thick section then a thin section followed by a thick section can pose problems *(see Fig. 17a)*. If both thick sections can't be properly gated the possibility of shrink or hot tear occurs.

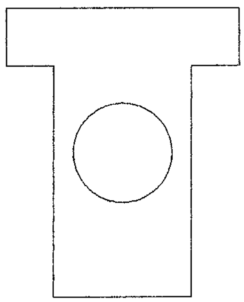

Figure 17a

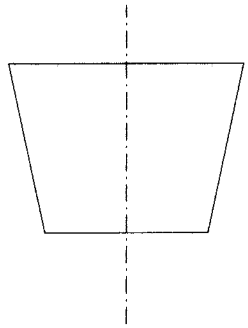

Figure 17b

Figure 17b illustrates an example of an ideal directional solidification casting design where the metal flows from a thick section to a thin section producing a sound casting. Parts without isolated thick sections will produce sounder castings.

Wall Thickness

The minimum wall thickness that can be achieved is dependent on material and the distance the molten metal must travel. Metal is poured at higher temperatures than the mold it is entering. Metal entering a mold is constantly losing heat. If the metal loses enough heat it will solidify before it has a chance to fill out all the detail of the mold.

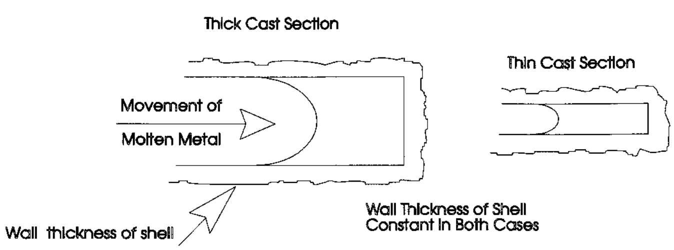

Figure 18

Since the mass of metal to mass of shell ratio is less in a thinner casting, as metal enters a thin section it is cooled to a much greater degree than when entering a thicker section *(see Fig.18)* and may not fill the thin section properly. Metal entering a thicker section of a casting has more mass, therefore a higher temperature is maintained and parts fill better.

Wall thicknesses of 1/8" over a distance of approximately 1" are possible. Wall thicknesses in aluminum can be as thin as 3/32" over a distance of 2" in length. Specific designs should always be discussed with the foundry.

Radii

Radii improve castability and generally improve part strength. In a casting, radii will help to dissipate heat improving solidification. A radius of a 1/64" to 1/32" or more is preferred for all internal or external corners. If a casting requires a zero radius on an internal corner (i.e. a casting that

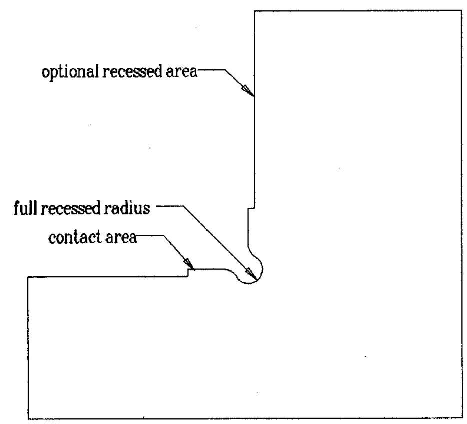

Figure 19

must mate with another part that has a sharp outside corner), a recessed corner as shown in Figure 19 can be used to provide relief. The recessed corner will also provide a part with greater strength as compared to a part with a sharp corner.

ENGRAVING

Engraving should be raised letters on a recessed pad, so the top of the engraving is below the surface of the part. This allows for engraving that is easier to produce without defect. Recessed engraving is less likely to interfere with the function of the part.

HOLE LENGTH

Making a good hole in a casting is dependent on the integrity of the shell. The ratio of hole diameter to length is important in determining what can be offered. Blind holes must have a radius at the top and the bottom of the hole to insure that a strong core is built for casting purposes and to insure the best possible casting results.

Hole Type	Size Range	Dia.to Length Ratio
blind	3/16 and up	1 : 1-1/2
thru	1/8 to 3/16	1 : 1
	3/16 to 1/4	1 : 1-1/2
	1/4 to 1/2	1 : 2
	1/2 to 1	1 : 3
	1 and up	1 : 4

GENERAL

Large flat surfaces can be improved by adding contour, such as holes or bosses. This can also help to improve the usefulness of the casting.

For repair of minor defects, in-process welding is a normal procedure for some alloys using a parent metal filler.

Some alloys cast better that other alloys. Sometimes changing to another alloy may make the part more castable, assuming part design is robust enough for such changes.

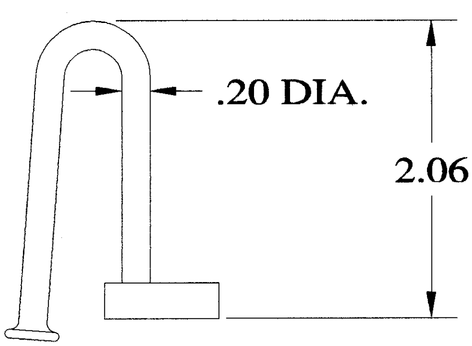

Figure 20

For example, Figure 20 was originally a fabricated design in low alloy carbon steel (1020). The customer wanted to reduce manufacturing costs by redesigning it as an investment casting. Pouring this part out of 1020 material, the part would be prone to more defects as a casting. What was needed from a castability standpoint was an alloy with good fluidity and the ability to resist hot tear as compared to 1020. Upon review, a change to 304 stainless steel was recommended. 304 stainless steel had the cast characteristics needed while meeting the customers design requirements.

This illustrates one of the main advantages of the investment casting process which is its broad alloy selection. No other manufacturing process offers as broad of a group of alloys to choose from than the investment casting process. This enables the designer to choose the alloy that is best suited for the application and will enhance the performance of the part.

If you have any questions regarding the technical information that has been provided, please contact us.
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