

# Casting Fundamentals

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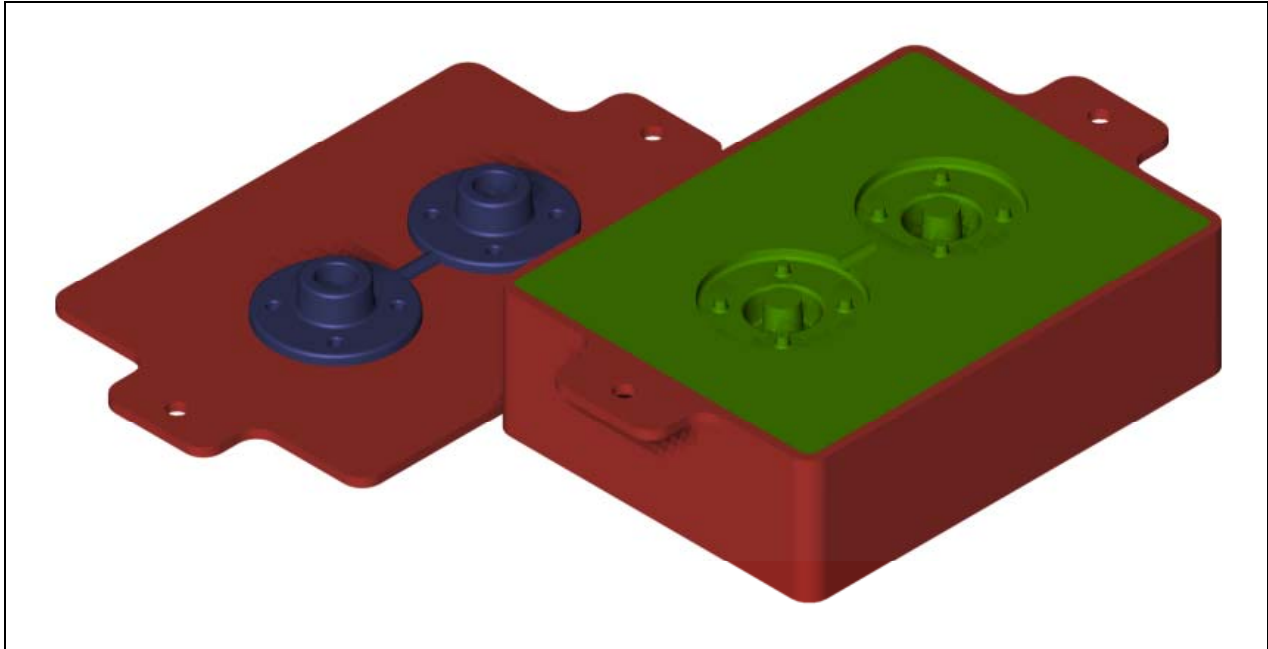
**In this chapter, you will learn the following to World Class standards:**

- 1. Why Use a Casting**
- 2. Setting Up to Pour a Casting**
- 3. Basic Principles of Designing a Casting**
  - 1. Surfaces perpendicular to the parting line will have a draft angle**
  - 2. Edges not on the parting line will be rounded**
  - 3. The cross sectional areas cannot change drastically in thickness**
  - 4. Use gussets and ribs to strengthen longer lengths**
  - 5. Add hubs where need a tapped hole**
  - 6. Add material for machining stock wherever the part needs to be finished**
  - 7. Know our casting specifications whether sand, investment or die cast to understand the industry standard tolerance for details in our design**
  - 8. Be well practiced in the placement of parting lines to gain the desired visual effect.**
- 4. Cost Savings Using a Cast Part**
- 5. Cast Part with the Parting Line on the End**
- 6. Cast Part with the Parting Line in the Middle**
- 7. Cast Part with the Parting Line Hidden**
- 8. Review the Basic Principles of Designing a Casting**

## Why Use a Casting?

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For thousands of years, people made molds from material such as sand, melted metals in crucibles and then after pouring the part, allowed for cooling. After opening the mold, workers spent time cleaning up the part, removing the extra material gained from the process in multiple areas. Where the two parts of the mold came together, the part can have excess substance called flash. There will be surplus material at the opening to the cavity and to the overflow area where the pourer determined the part had enough metal.



**Figure 5.1 – The Tools Used for Casting Parts**

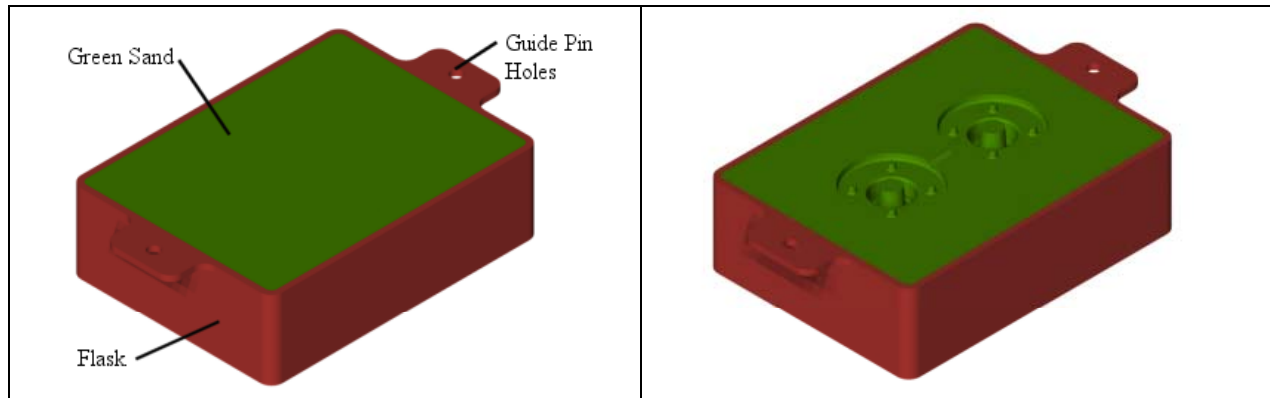
A casting is nearly a perfect process where by planning the creation of the mold correctly, we can reduce the amount of secondary manufacturing processes to almost zero. Assuming a designer needs to have a metal part such as a cast iron base plate, a properly trained engineering technician can produce a drawing where the company will only pay for the foundry setup, the metal, minor part clean up and part shipping. If an individual did not know the process, their organization many times compensates the foundry for part design, and their own manufacturer may have to machine the part to obtain a detail, which should have been cast.

First we will learn the parts of the mold by learning the names of the

<b>Cavity</b>	<b>Flask</b>	<b>Pattern</b>
<b>Cope</b>	<b>Gate</b>	<b>Riser</b>
<b>Core</b>	<b>Green Sand</b>	<b>Rounded Edges</b>
<b>Draft Angle</b>	<b>Guide Pins</b>	<b>Sprue</b>
<b>Drag</b>	<b>Match Plate</b>	
<b>Flash</b>	<b>Parting Line</b>	

## Setting Up to Pour a Casting

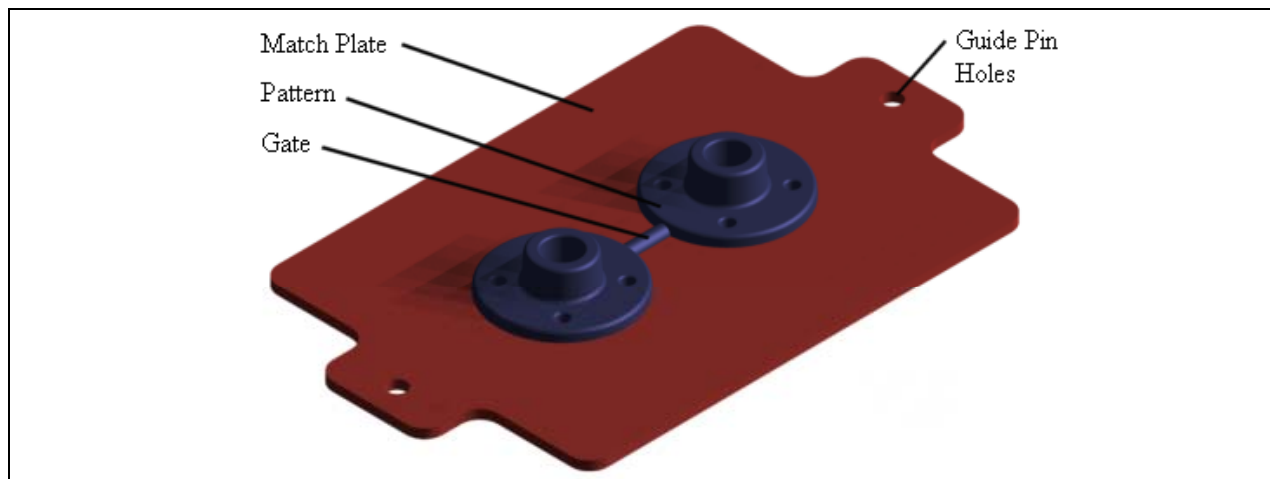
At the foundry, a shell called a **Flask** is set on a flat surface. The foundry worker fills the **Flask** with **Green Sand**, which is a special type of sand that binds together tightly. The worker will use a hammer or vibration tool to compress the sand in the **Flask**. They definitely do not want any cavities or weak spots in the sand. Next, the technician will take the **Match Plate**, a special flat surface that contains the **Pattern**, and presses the imprint of the part into the sand. There are **Guide Pins** on the end of the **Match Plate** and the **Flask**, which allow both sides of the **Cavities** to align perfectly. Since the bottom half of the mold, which is called the **Drag** is done, the employee now continues to the other side, the **Cope**.



**Figure 5.2 – Green Sand in the Drag**

**Figure 5.3 – After Pressing the Match Plate**

We call the top side of the mold, the **Cope**. The worker fills a second **Flask** using the same process as with the **Drag**. The worker places a **Match Plate** on the **Flask**, matching the guide pins, making a cavity in sand for the part. Not all castings have impressions in both sides of the mold. Now in the **Cope** the worker will add two special holes. The first hole, which we call the **Sprue**, is to allow metal to be poured into the sand cast. The second hole, which we call the **Riser**, allows the technicians to check whether the cavity is filled with metal. The second hole also allows air to escape the **Cavity** of the mold, so the part does not contain imperfections.

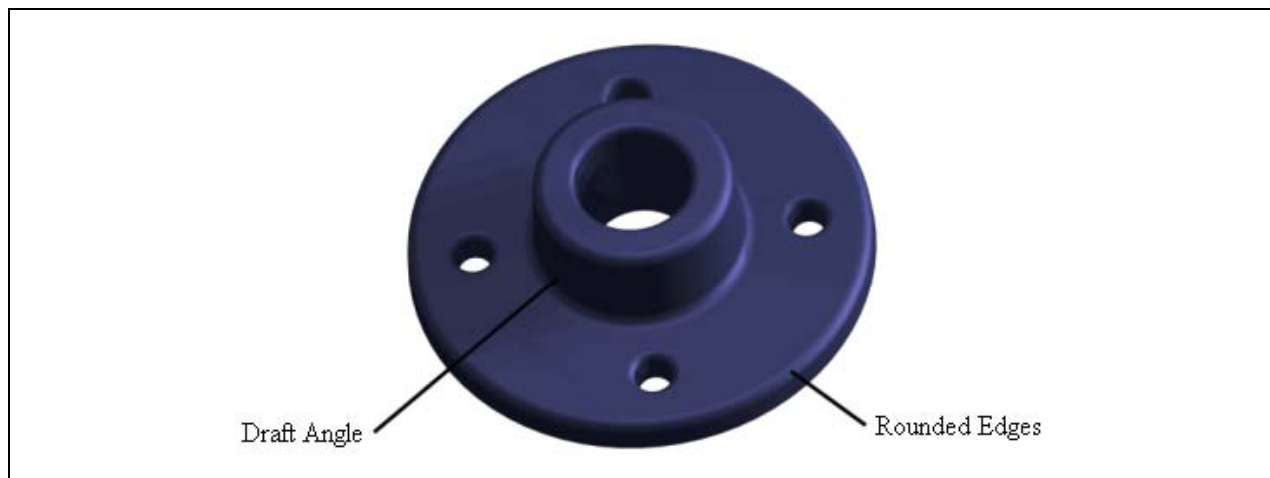


**Figure 5.4 – Components of the Match Plate**

Notice there are other several important details we can see in the **Pattern**, which sets on the Match Plate as shown in Figure 5.4. First in our example, we can see two copies of the same part, which allows the foundry to produce twice the number of parts when making up a single sand cast. Now we can see the **Gates**, which are channels that join the two impressions and allow the metal to flow throughout the **Cavity**. There is a slope or **Draft Angle** in the sides of the **Pattern**, which allow the worker to press the imprint of the part into the sand, and to remove the **Pattern** without damaging the integrity of the walls.

When the designer wants to place a hole parallel to the direction of pressing the pattern into the sand, we use a **Core**. The core is also made from **Green Sand** and is baked in an oven to create a very solid entity. The worker places the **Core** into a nest that the **Pattern** maker built into the detail on the **Match Plate**. Now we place the **Cope** on top of the **Drag**. The plane where the two molds come together is called the **Parting Line**. Depending on the accuracy of the making the sand cast, small amount of metal called **Flash** can result at the end of the cooling process. The foundry personnel will use a hand tool or trim die to remove the **Flash**.

There are **Rounded Edges** on the all the surfaces of the pattern. Why do we see that type of detail? The fact is that a sharp corner takes longer to cool. In our materials class when studying to be an Architect or Engineer, we will learn that by cooling material at different rates will result in diverse stresses in the final product. If we place too sharp of an edge at any corner, the result will be a broken surface and a quality control person will reject the casting.



**Figure 5.5 – The Finished Cast Part**

Another piece of valuable information to pass along to designers is using an advanced Rapid Prototyping machine, a mechanism that will create the actual pattern from a stereo lithography computer file (.STL). Another piece of data affecting their casting pattern is that the hot cast part will shrink during the cooling process. Tool designers making patterns always calculate the shrinkage and apply the shrink rate to the size of the pattern. If we ever check a pattern against our manufacturing computer aided design drawing, notice the pattern will be proportionally larger.

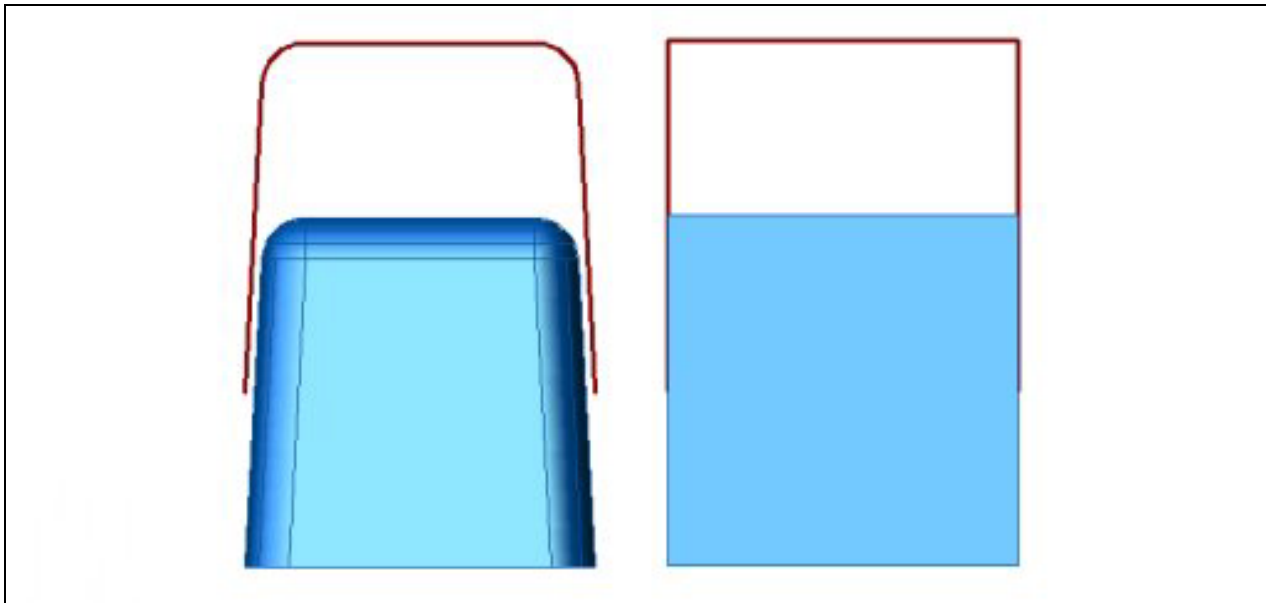
We may want to check our local yellow pages to locate a prototype producer in our region to assist us in fabricating sample castings and they can create patterns allowing us to pour several test parts at our own facility made from plastic.

## Basic Principles of Designing a Casting

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### Surfaces perpendicular to the parting line will have a draft angle

Now that we know a little about the casting process, we now can venture towards the casting design process. Foremost as a designer of castings, we will need to remember that surfaces perpendicular to the parting line will have a draft angle. We have made ice cubes in the freezer and we will notice the draft angle in the form of each impression in the ice cube tray. When we break the contact surface of the plastic ice cube tray and the ice, immediately the single ice cube can fall away. Likewise, we have tried to get a cylinder of frozen juice from the container. Even after remove the lid, the frozen contents must slide out the length of the tube and the sides are in constant friction the entire duration. In Figure 5.6, we can visualize the difference between the casting breaking contact with a wall with a sloped angle engagement and when two sides are parallel. For sand castings, design at least a three-degree draft angle into the sides of the wall.



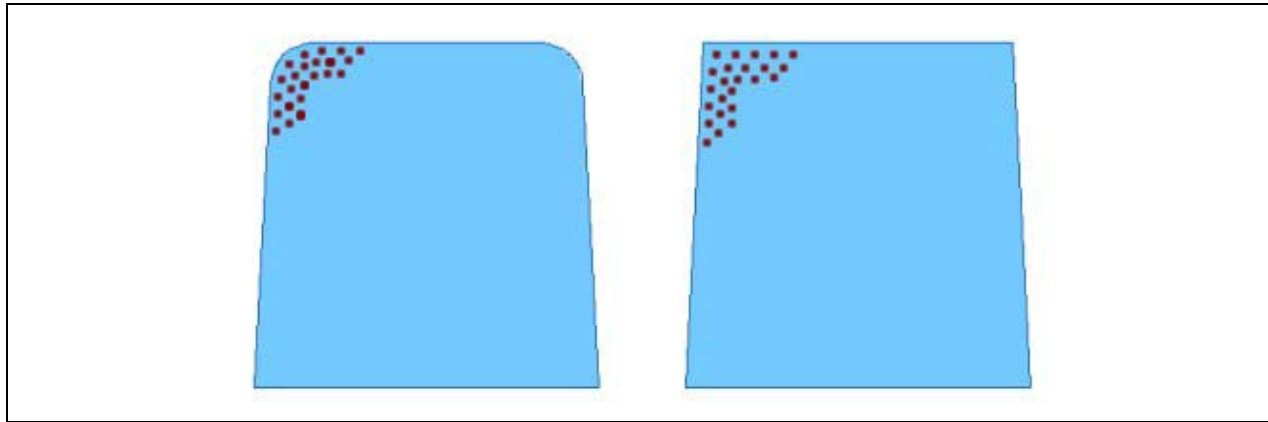
**Figure 5.6 – Removing an Casting from the Green Sand**

### Edges not on the parting line will be rounded

Another rule of constructing a casting is to place rounded edges whenever possible. In Figure 5.7, red dots in the cross section of both castings represent heat units trying to escape the hot metal part when the casting is cooling. In the illustration on the left, each heat unit has equal distance to move to the surface and escape into the atmosphere. In the illustration on the right, the heat unit at the corner must move a longer distance to gain the surface and break out into the environment.

With the a casting having straight edges, think that the heat particle in the corner would travel the distance equal to the hypotenuse of a  $45^\circ$  triangle (1.414), where the particle on the sides only travel a distance of one. On the casting with the rounded edges, the lengths the particle

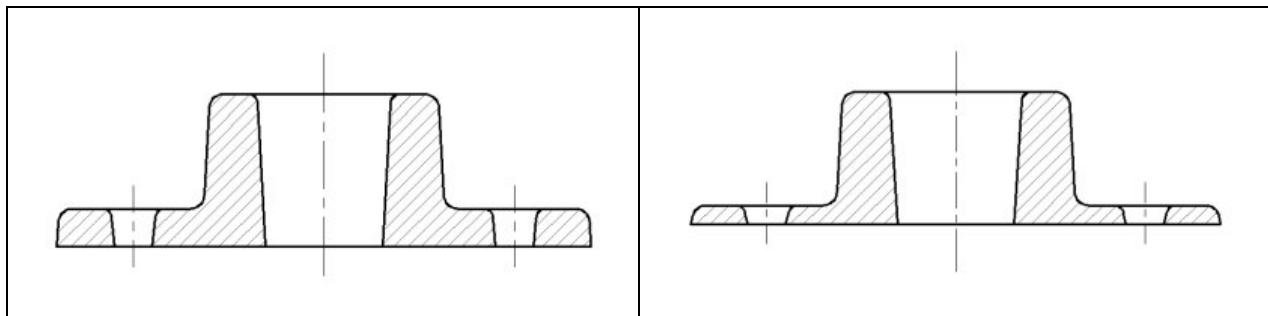
must travel while on the curved edge are a leg distance of one and therefore the casting cools evenly. We can make the rounded edge very large, but as a designer, we need to consider the functionality of the part as well as cooling.



**Figure 5.7 – Cooling a Rounded Edge Versus a Straight Edge**

The bottom of the casting shown in Figure 5.7 is not rounded, since this is the plane where the pattern is attached to the match plate. If we desire to have rounded surfaces on every edge, then place the parting line in the middle of the part.

**The cross sectional areas cannot change drastically in thickness**



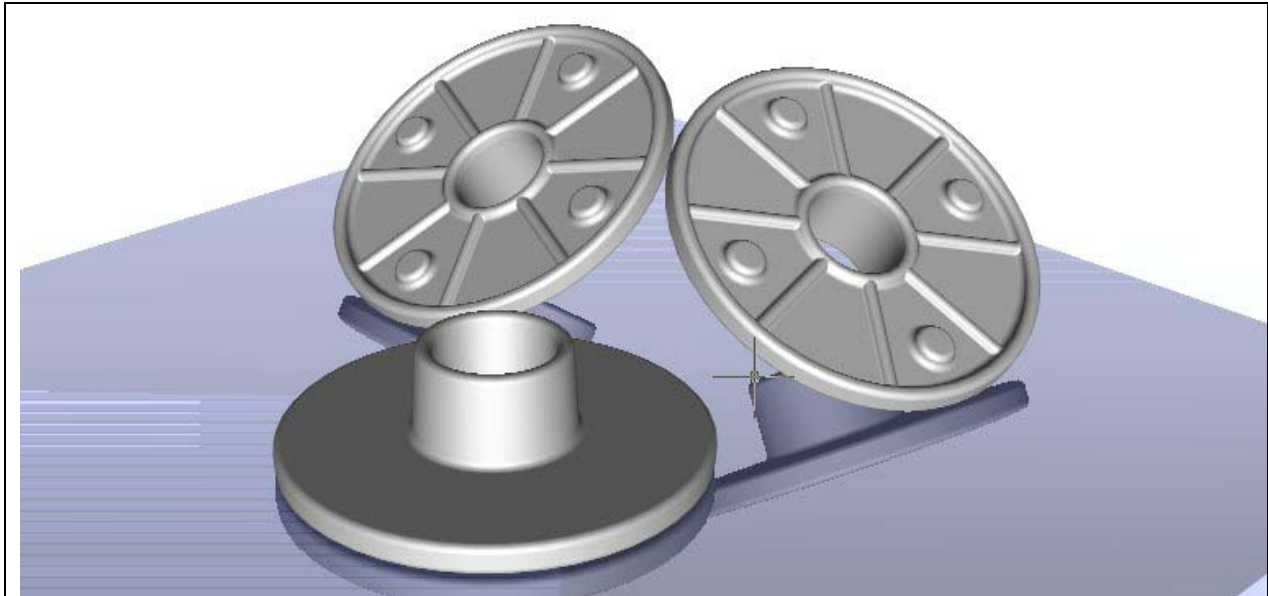
**Figure 5.8 – Good Equal Cross Sections**

**Figure 5.9 – Poor Equal Cross Sections**

A third precept of casting design is governing the interface thicknesses between different cross sectional areas. In Figure 5.8, the finished cast hub has relatively the same thickness in the vertical section as well as in the horizontal segment. This type of design allows for equal cooling throughout the casting process. In Figure 5.9, the cross sections of this cast base is not equal. The part will fail at the base of the large hub where the thin flange works outward. Try to keep the cross sectional thicknesses equivalent throughout our design.

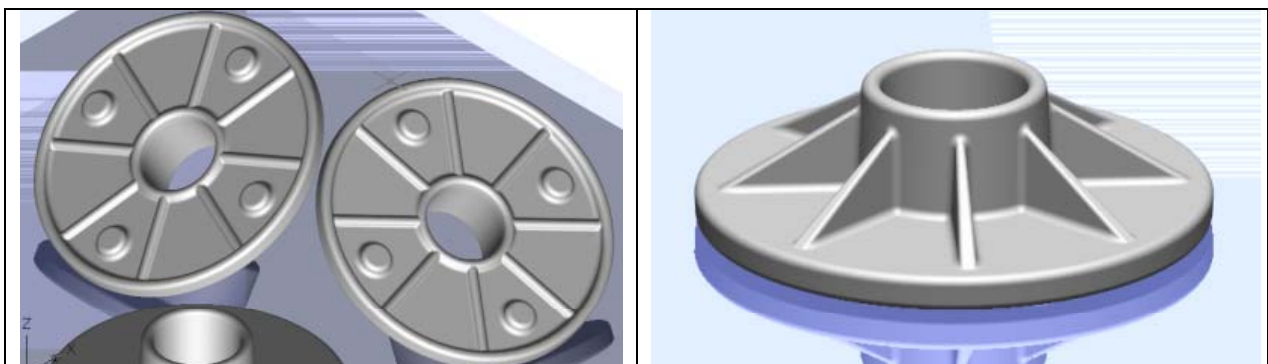
Whenever we are in doubt about the design of our casting, we can send a copy of the computer aided design drawing to the foundry and allow the pattern maker or sales engineer to review our work. They can point out details, which can assist in making our casting efficiently. Teamwork in product design is very important to guarantee a quality product. The pattern maker or foundry professional can add years of experience to our design team, so take their advice as well as pointing out to them critical areas that we must be retain in our own design.

## Use gussets and ribs to strengthen longer lengths



**Figure 5.10 – Castings with Ribs and Bosses**

Imagine that we would want to redesign the cast base shown in Figure 5.5 and our employer would like us to remove some weight from the part, yet we must retain the strength. In Figure 5.10, we can see the flange or horizontal section of the base is now almost 50% less material. The hub or vertical section also has been reduced in thickness, so we will have a uniform cross section in the casting for even cooling. There is a lip on the outside of the flange and on the inside area below the hub. As we can observe in Figure 5.11, eight ribs are placed at 45-degree angles evenly in the 360-degree circle. The ribs will strengthen the flange to resist torque, tension and compression on the top of the base. The outer ring on the flange will give the part the greatest strength. We can see in Figure 5.12 that 45 degree ribs called gussets also can run from the top of the flange to the hub, since many designs will not allow for the interferences caused by details on the outside surfaces of a component.



**Figure 5.11 – Adding Ribs and Bosses**

**Figure 5.12 – Considering Gussets**

## **Add hubs or boss where we need a tapped hole**

Instead of increasing the cross sectional thickness of the casting if we are require to add a tapped hole or press a tapped insert into the casting, place a hub in the cast part. In Figure 5.10, we can distinguish four bosses that can have holes drilled into them. In the original cast base, we see the four clearance holes that are spaced 90 degrees apart. In the new casting with thin walls, four 0.75 diameter bosses are  $\frac{1}{4}$  high off the inside wall. Four clearance holes could be drilled in these locations or each space can have a drilled hole with tapped threads. By leaving the clearance hole out of the design, this part can have different uses depending upon the application.

## **Add material for machining stock wherever the part needs to be finished**

We add machining stock to a surface whenever we decide that the particular area will need to be machined by drilling, broaching, facing or any other process requiring some thickness to machine to a 125 micro-finish of better. A good rule is to add 0.100 to 0.125 addition material where the metal part needs machining. This machining area can become thicker depending upon the draft angle we wish to use.

## **Know our casting specifications whether sand, investment or die cast to understand the industry standard tolerance for details in our design**

Each industry governing the different styles of castings has written specifications that are published and define the standards for designing components. The common types of casting processes are sand castings, investment castings and die castings. The sand casting foundries make parts using lower production numbers, typically under 1000 pieces a year, but the tooling is less expensive. Tolerances for sand cast parts are larger, up to  $\pm 1/16$ " on each dimension. The investment casting process comes after sand casting and before die casting, since the dimensional control is better. The tooling and manufacturing setup can be greater than for the sand casting process, so companies look for a higher production number of 5000 to amortize the higher manufacturing price tag. Finally, we will consider the die casting process where tooling can cost from ten to hundred of thousands of dollars. Our business will need production numbers past 10,000 pieces a year to start to justify the addition tooling cost. The die casting will offer the designer the best dimensional and surface control of all the processes.

<b>Industry</b>	<b>Standards Group</b>	<b>Web Site</b>
Sand Castings	American Foundry Society	<a href="http://www.afsinc.org">http://www.afsinc.org</a>
Investment Castings	Investment Castings Institute	<a href="http://www.investmentcasting.org">http://www.investmentcasting.org</a>
Die Castings	North America Die Cast Assoc.	<a href="http://www.diecasting.org">http://www.diecasting.org</a>

**Figure 5.13 – Some Resources in the Casting Industry**

## **Be well practiced in the placement of parting lines to gain the desired visual effect.**

In the next section of this chapter, we will be studying how to place the parting line on a cast part using a simple ice cube shape to learn each technique. There are advantages and disadvantages for each method and we need to comprehend the basic placement of the parting

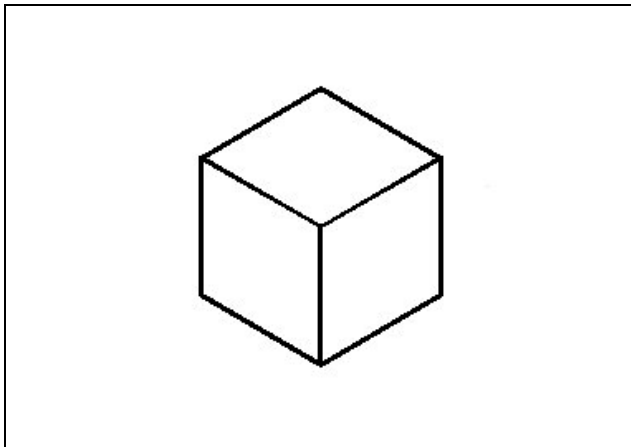


line. How the parting line is located on the part affects tooling cost, part cost and overall aesthetics of the finished product. The first method will have us place the parting line on the end of the part, which is the cheapest method when only a single match plate pushes the impression of the part into the green sand. The second way we will study is a common process for cast parts where the parting line is in the middle of the component. For symmetrical parts, we can still use the same match plate to place the imprint of the pattern into both sides of the mold. The third process is to understand how to hide the parting line at the transition to a rounded edge. This last technique will help in the overall artistic feel of the part.

## Cost Savings Using a Cast Part

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Why would we definitely want to consider a casting when producing our part? Well we need to look at a 1-inch cube to make comparisons in price. If we purchase 1 by 1 aluminum bar stock from the local material distributor at \$2.50 a pound and cut the part at 1 inch, we will have a 1 by 1 by 1 cube. The density of the aluminum is 0.1 pounds per cubic inch, so the weight of the part is 0.1 pounds. Multiply the 0.1 times \$2.50 and the cost of the material for the part is \$0.25. The cost of cutting and finishing the cube is \$0.58 for a total cost of 83 cents. That does not sound like much for a finished part, but now we need to compare our piece price to the cost of a casting. When we do, we will discover that we can get a very similar shaped part for a fraction of the cost of a machined milled shape. Yes, we have to deal with parts with tapered sides and rounded edges, but in many cases, the customer likes to have the smooth silhouette.



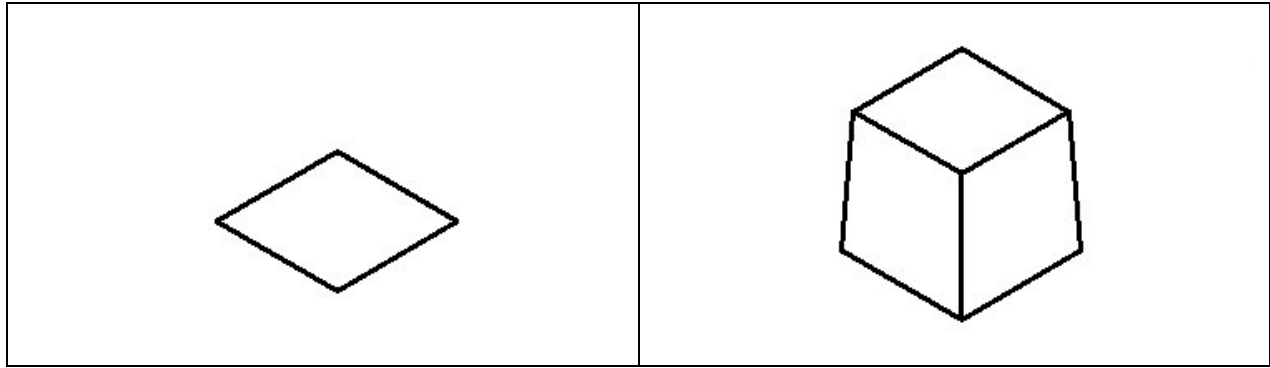
When trying to compute the cost of a part, in many instances the part weight will be required to estimate the price of a single piece. In the AutoCAD software, select the Massprop tool on the Inquiry toolbar. Select the solid. The AutoCAD application will generate a report that will contain the part's volume in cubic inches. Multiply the volume by the density of the material in pounds per cubic inch. In this exercise, the part is 1 cubic inch times 0.1 pounds per cubic inch, so therefore the answer is 0.1 pounds.

**Figure 5.14 – 1” Cut of One Inch Bar Stock**

## Cast Part with the Parting Line on the End

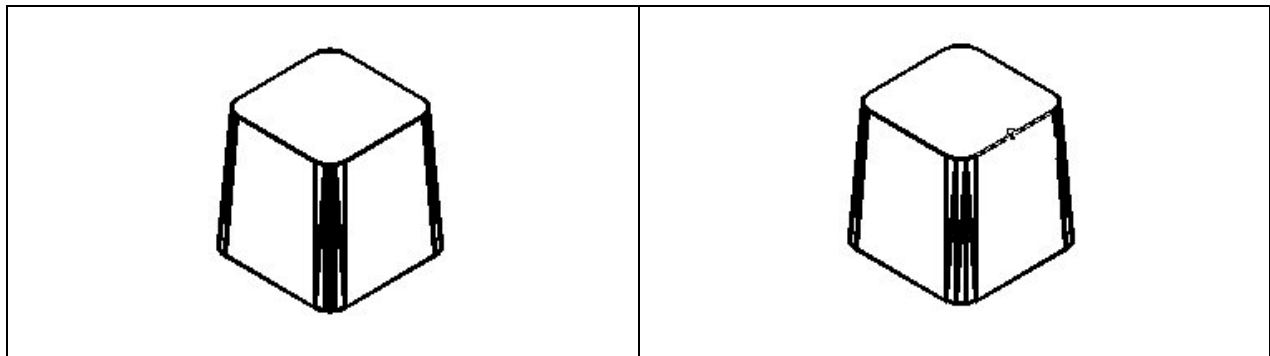
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The most common sand casting will have the parting line on the very end of the part. In our CAD software, draw a 1 x 1 base as shown in Figure 5.15 and extrude the entity one inch at a 3° angle as shown in Figure 5.16.



**Figure 5.15 – Start with 1 x 1 Square**

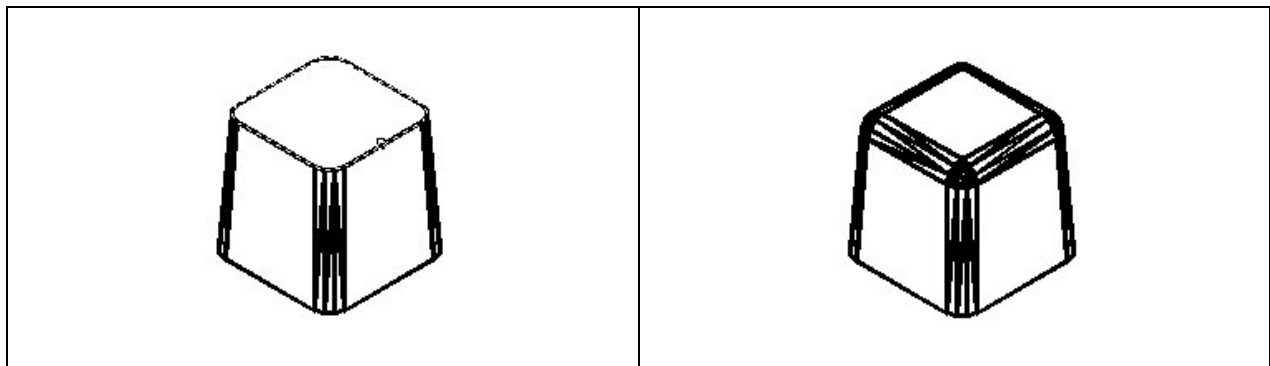
**Figure 5.16 – Extrude 1 Inch at 3 Degrees**



**Figure 5.17 – Add 1/8 Rounded Corners**

**Figure 5.18 – Select the Top Edge**

Now, we need to add a fillet radius on all four edges of 1/8 inch as shown in Figure 5.17. Finally, place a chained fillet of the 1/8 radius on the top of the casting by picking one of the top lines as shown in Figure 5.18. After opting to chain the radius, select the same edge as shown in Figure 5.19.



**Figure 5.19 – Chain the Selection**

**Figure 5.20 – The Finished Casting**

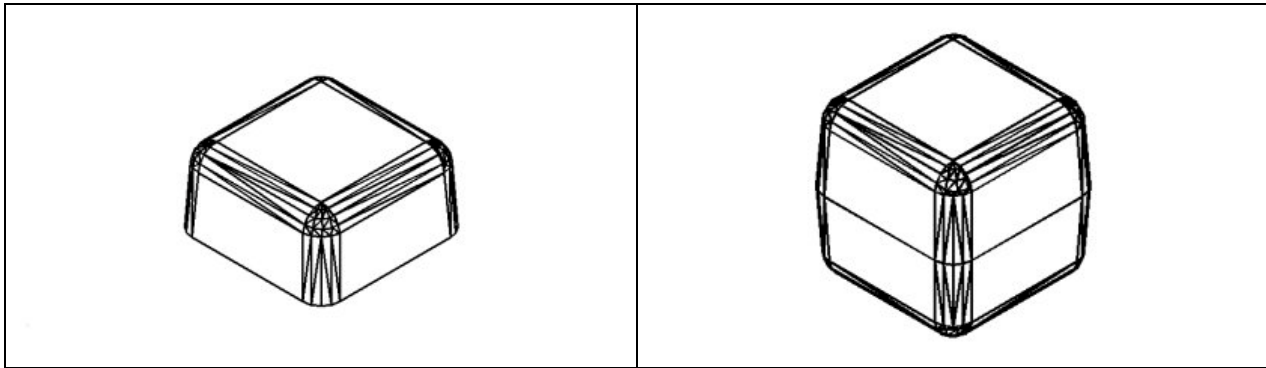
We will place the casting that has the parting line on the bottom of the solid as shown in Figure 5.20 right on the match plate, so the part can be pressed into the green sand making a cavity for the part. Having a single match plate will save us money on the pattern cost. Now to figure the cost of the first casting, determine the volume of the casting in Figure 5.20. By using a Massprop tool in the AutoCAD program, we can see that the volume of the casting is 0.876

cubic inches. The density of the aluminum is 0.1 pounds per cubic inch, so each casting will weigh  $0.876 \times 0.1$  or 0.0876 pounds. Now, we can contact the aluminum foundry and discover that the cost of pouring D712 aluminum, which makes very nice castings, is \$1.05 per pound. Multiply 0.0876 pounds times \$1.05 per pound, which equals 9.2 cents per finished part. Comparing our cast of \$0.092 to the machining cost of \$0.83, we could expect more professionals to consider a casting to fabricating from a milled shape. The determination will come down to whether we need one part or fifty. We can use a spreadsheet to determine how many parts we need to use annually to justify the tooling cost of making a pattern.

## Cast Part with the Parting Line in the Middle

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Previously, we heard that a cast part could contain all rounded edges, which will help the component to cool efficiently. The next casting process we will learn is to place the parting line in the middle of the cube so the part will rise 0.5 inch at three degrees from the match plate. We will need to place the same 1/8 radius on the sides and top edges of the solid.



**Figure 5.21 – Half of the Cube**

**Figure 5.22 – The Entire Cube**

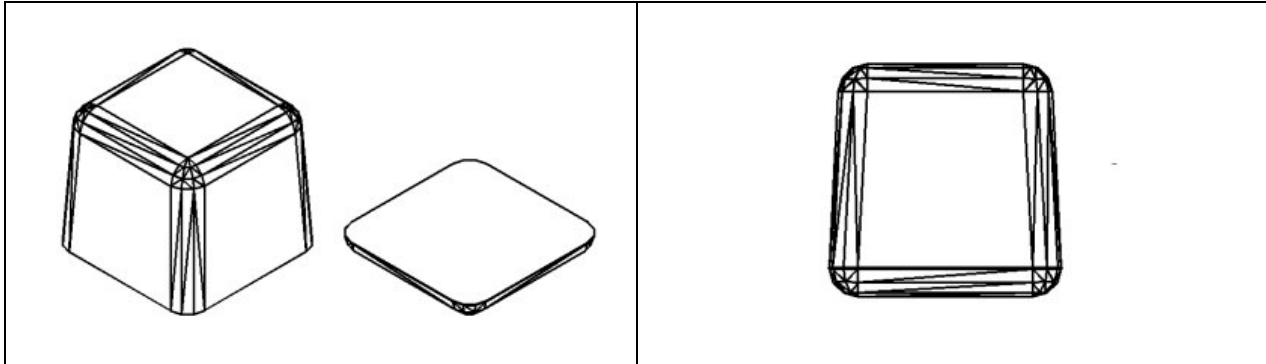
In our CAD software, draw a 1 x 1 base as we did before in the first casting and extrude the entity 0.5 inch at a  $3^\circ$  angle. Now, we need to add a fillet radius on all four edges of 1/8 inch. Finally, place a chained fillet of 1/8 radius on the top of the casting by picking one of the top lines as shown in Figure 5.21, and chain all four top lines together. To finish the casting, select the half cube in Figure 5.21 and mirror the part using the bottom of the casting as the mirror plane. Save both sides of the casting and the finished part will appear as shown in Figure 5.22. Union the two sides top and bottom together.

When the pattern maker designs the tooling for the second cube, a single match plate can still be used in this case since both cast section are symmetrical. This will save us money on the pattern cost. Now to figure the cost of the second casting, determine the volume of the casting in Figure 5.22. By using a Massprop tool in the AutoCAD program, we can see that the volume of the casting is 0.915 cubic inches. The density of the aluminum is 0.1 pounds per cubic inch, so each casting will weigh  $0.915 \times 0.1$  or 0.0915 pounds. Now, the cost of pouring D712 aluminum, which makes very nice castings, is still \$1.05 per pound. Multiply 0.0915 pounds times \$1.05 per pound, which equals 9.6 cents per finished part. Comparing our second casting cost of \$0.096 to the first cast part of \$0.092, this option of placing the parting line at the midpoint is worth considering. The second part is more aesthetically pleasing.

## Cast Part with the Parting Line Hidden

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In the second cast solid, we can see the parting line on the finished component. The next process we will learn is to hide the parting line at the transition to the rounded edge. On the one by one by one cube with a 1/8 radius, which means we will extrude one section 7/8 in height at three degrees from the match plate and the other section will be 1/8 tall rising at three degrees from the match plate. We will need to place the same 1/8 radius on the sides and top edges of the solid.



**Figure 5.23 – 7/8 and 1/8 Extruded Sections**    **Figure 5.24 – Finished Casting**

In our CAD software, draw a 1 x 1 base and extrude the entity 0.875 inch at a 3° angle. Now, we need to add a fillet radius on all four edges of 1/8 inch. Finally, place a chained fillet of 1/8 radius on the top of the casting by picking one of the top lines as shown on the left side of Figure 5.23, and chain all four top lines together. Repeating the process, draw another 1 x 1 base and extrude the entity 0.125 inch at a 3° angle. Now, we need to add a fillet radius on all four edges of 1/8 inch. Finally, place a chained fillet of 1/8 radius on the top of the casting by picking one of the top lines as shown on the right side of Figure 5.23, and chain all four top lines together. To finish the casting, move both sections in Figure 5.21 and matching together the bottom of the 7/8 tall section and the top of the 1/8 high section. Union the top and bottom sections together and the finished part will appear as shown in Figure 5.24.

When the pattern maker designs the tooling for the second cube, a two match plates need to be used in this case since both cast section are not symmetrical. This will cost us money on the pattern cost. Now to figure the cost of the second casting, determine the volume of the casting in Figure 5.22. By using a Massprop tool in the AutoCAD program, we can see that the volume of the casting is 0.887 cubic inches. The density of the aluminum is 0.1 pounds per cubic inch, so each casting will weigh 0.887 x 0.1 or 0.0887 pounds. Now, the cost of pouring D712 aluminum, which makes very nice castings, is still \$1.05 per pound. Multiply 0.0887 pounds times \$1.05 per pound, which equals 8.9 cents per finished part. Comparing our third casting cost of \$0.089 to the second cast part of \$0.096, this option of hiding the parting line at the rounded edge also should be considered. Remember in this third case, the tooling to make multiple patterns will raise the initial cost of developing our multiple match plates.

## Review the Principles of Designing Castings

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Before venturing on to the next chapter and creating advanced casting parts, we need to understand each of these simple yet important design rules. In our first years of design training, an engineer will have to compute the strength of the casting for us. We may have seen the other data in the Massprop report, Like the Center of Gravity or Moment of Inertia in each axis. To examine a cast part independently for strength, move the Center of Gravity of the casting to the origin. Now, rerun the report and the numbers will make more sense.

Only through practice and efficient use of 3D software will we be able to consider every factor, such as tooling cost, part cost and overall aesthetics of the finished product. Just understanding 3D computer aided design drafting is not enough. We can design a 3D model on our computer that would cost hundreds of thousands of dollars in tooling cost, because we did not take each surface in our design in consideration. Many times, we see the part design compromised once the designer turns over control of the project to the pattern maker, who makes changes and the finished casting cannot pass the final engineering tests. Sometimes after the tooling is made and the part fails the engineering tests, the original match plates of jigs cannot be salvaged and the process starts all over from square one. Basic principles and considering more than one approach is important. Having the computer drawing speed is excellent, because we will allow for those multiple models. Three-dimensional rendering allows us to show the customer and all others involved to view all the choices. 3D models can be stressed using Finite Element Analysis programs, which will allow for accurate data before the first part is produced. Review and post the casting design principles so we do not forget them.

### Basic Principles of Designing a Casting

1. Surfaces perpendicular to the parting line will have a draft angle
2. Edges not on the parting line will be rounded
3. The cross sectional areas cannot change drastically in thickness
4. Use gussets and ribs to strengthen longer lengths
5. Add hubs where we need a tapped hole
6. Add material for machining stock wherever the part needs to be finished
7. Know our casting specifications whether sand, investment or die cast to understand the industry standard tolerance for details in our design
8. Be well practiced in the placement of parting lines to gain the desired visual effect.
  - a. Cast part with the parting line on the end of the component
  - b. Cast part with the parting line in the middle of the component
  - c. Cast part with the parting line hidden

**\* World Class CAD Challenge 08-10 \* - Create a New file and draw the 1 x 1 x 1 solid using the techniques in this chapter. Next, you need to draw a 1 x 1 x 1 casting with a 3° draft angle and 1/8 radius edges. For the second casting, create a 1 x 1 solid with the parting line in the middle. For the last casting, draw a 1 x 1 solid with the parting line hidden in the transition to the 1/8 rounded edge. The drawing can appear as shown in Figure 5.25. Continue this drill four times, each time completing the drawing under 15 minutes to maintain your World Class ranking.**

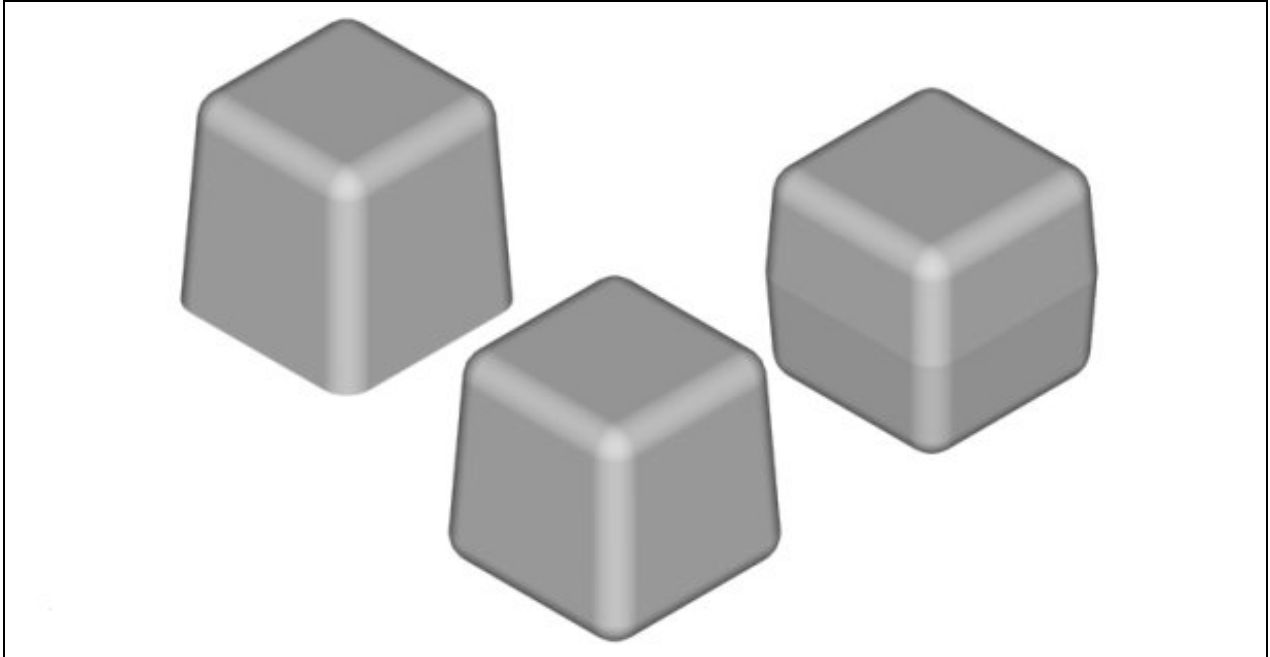


Figure 5.25 – Three Cast Cubes