Edited by Dr. Jerry Thiel

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Casting Design Guidelines
Information on the design requirements of steel and iron castings
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The ESP Advantage - Engineering Support

Our experienced team of degreed engineers can help develop a casting for your specific product application.

Trained in product design and development, utilizing Pro/engineer and Mechanica, our engineers will design a casting that can reduce costs, trim weight and outperform an existing component.

Design Example:
Tillage Shank Mount
We were asked to design a casting to take the place of a weldment in a large piece of tillage equipment.

The customer had previous issues with the mounting pins breaking in application. And the casting had to be designed to reduce the breakage seen in application.

The cast design proposed combined the two weldments into one, reducing overall component costs, assembly labor, factory part count and as shown below reduced a failure in the application.

With the loading applied to the weldment the FEA revealed the design issue.

After reviewing the weldment FEA, we were able to propose a cast design that moved some of the strain into other areas of the part. Reducing the stress at the base of the pin.
The ESP Advantage - Quality Control

Quality control is one of the crucial elements of successfully sourcing a product globally. We have overcome this concern through building relationships with our global casting partners by defining and documenting our expectations with them.

Most importantly, quality control is performed by our quality lab located on the ground in the country where ESP sources your parts. ESP’s Supplier Quality Engineers are deployed for onsite inspection of first articles as well as production runs of your parts. All of this helps to keep the quality level of your parts at the level you demand.

Quality Equipment List:

Material Inspection:
Optical Emission Spectrometer
Fourier Transform Infrared Spectrometer
Bench top Hardness Tester
Tensile Test Machine

Dimensional Inspection:
Surface Profilometer
Romer arm®—portable CMM
Visual CMM
CMM
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Introduction to Metal Castings

ESP International is a global supplier of machined steel, iron and aluminum castings. ESP is located in Cedar Rapids, Iowa and currently has sources and joint ventures for a variety of metal castings in the US, China, India, and Taiwan.

The following pages provides a brief look into metal castings, with a focus on today’s processes and materials for steel and iron. The information presented will raise questions about castings. Why use a casting? What kind of materials fit the application? What can I expect from the casting process? We will attempt to answer all of these questions in the following pages.

It is the intention that this guide will provide enough information to direct a designer or buyer to a particular casting process and material that can meet their design and cost criteria.

What are Metal Castings?
A metal casting can be defined as a metal object formed when molten metal is poured into a mold which contains a cavity of the desired shape and is allowed to solidify.

The casting process is used most often to create complex shapes that would otherwise be difficult or impossible to make using conventional manufacturing practices.

History of Castings
The first casting on record is a copper frog from Mesopotamia, dated to around 3200 BC. Iron, a more common material cast today, was discovered in China around 2000 BC and first used iron in a casting process around 600 BC.

Cast steel is a more recent develop-
Metal Casting in a Global Market

Today’s Global Market

A continuing challenge for anyone involved with manufacturing or producing a product is keeping costs down. One solution is to source product in low cost countries. Utilizing a casting design will help realize the cost benefits of castings, but pairing that with a low cost source while maintaining quality takes that savings to the next level, and is ESP’s forté.

Today metal castings are produced on a global scale. Figure 4 gives a snapshot of the global metal casting market today, with China and India playing a major role in the production of metal castings.

One of the main concerns when sourcing a product globally is part quality. India and China both have the ability to compete on a global scale as far as part quality. What is important as a buyer of global castings is maintaining a level of quality control on your parts. The fact that you could be many time zones away only makes it more difficult to control the quality of a product.

ESP has overcome this by building relationships with our global casting suppliers and by defining our expectations. And most importantly, quality control is performed by ESP’s SQE’s and quality lab, located on site in the region where your parts are sourced. Supplier Quality Engineers are deployed for onsite inspection of first articles and supplier audits. Close monitoring of production part manufacturing ensures that the quality of your parts will meet the level you demand.

Global Metal Production

![Global Metal Production Chart](image)

Data from American Foundry Society.

Figure 3 - Global Casting Market

Global Metal Production

![Global Metal Production Chart](image)

Figure 4 - Global Casting Market

The Casting Process

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Investment Casting

Investment Casting Process
The shell mold investment casting process starts out with the creation of a wax mold, from which the wax pattern is made. This wax mold must be sized to account for two shrink factors, one for the wax itself and the other for the steel.

After enough wax patterns are produced, a pattern assembly or tree is created. Here the wax patterns are glued onto a main gating system.

Once the pattern assembly is complete it is then coated in a ceramic slurry. After each dip the wet pattern assembly is then placed in a fluidized bed of sand for coating. Another method is to rain refractory material over the wet pattern assembly.

After each dipping cycle of ceramic slurry and sand coating, the pattern assembly is allowed to dry thoroughly before the next coating. The number of coatings required is dependent on the size of the metal casting and the temperature of the alloy being poured.

Once the ceramic shell is complete, the shell is placed upside down in an autoclave and the wax is removed and reclaimed from the shell.

The shell is then fired, to 1800 °F (982 °C), which is necessary to burn out any left over wax and any moisture that may be present in the shell.

These shells can then be stored or immediately poured. If the shells are stored they will need to be preheated before pouring.

The shells can be gravity poured in air or under vacuum. After the castings have cooled completely, the shell is removed and the castings will be cut from the tree.

There are variations of this process across the globe. The type of refractory material used can vary from a true ceramic to a silicate or sand material. The ceramic investment cast process will yield a casting with an excellent surface finish, while the silicate investment cast will yield a casting with a rougher, sand cast like, surface finish, but with a lower part cost.
Investment Casting

Injecting Wax

Ejecting Pattern

Pattern Assembly

Slurry Coating

Sand Coating

Dewaxed

Shell Mold Fired

Pouring

Shakeout

Finished Casting

Figure 5 - The Investment Casting Process
Sand Casting

Sand Casting Process
All sand casting processes start out with the creation of what is termed tooling. This tooling consists of a pattern which is a positive replica of the part and forms the outside surfaces of the casting. On horizontally parted patterns the top half of the pattern is called the cope and the bottom half is called the drag. Sand cores form the internal surfaces of the casting and are made from tooling named core boxes. The cost for casting tooling is usually separate from the cast part cost or may be amortized over a specified quantity of castings.

It should be noted that all tooling is not created equal. The size and type of equipment available for molding will often determine what mold materials can be used. Hand molding, which is typically used for lower production volumes, will use a lighter weight material for the mold, such as wood, plastic or aluminum. Automated molding will require a steel or tool steel in order to maintain the mold life at a reasonable level.

Mold Making Processes
After the tooling is created a mold is made from that pattern. In sand casting there are many different processes used to create molds. The two most common methods are:

Figure 6 - The Sand Casting Process
Sand Molding Process

1. Green Sand Molding

Green sand molding is the most common process for making molds for small to medium size metal castings. Typically a silica sand is used with a mixture of bentonite clay and water. This coating of clay and water allows the sand grains to stick together when compacted against a pattern surface. The sand mixture is compacted in a removable flask that is attached to the pattern. After the sand is compacted the pattern is removed revealing a cavity in the sand mold. This sand mold is used only once and sand recycled after use.

2. No Bake Molding

No bake molding uses a polymer resin instead of clay and water to hold the sand in place. The term no-bake comes from the early forms of resins where heat was required to bond the sand. Current resins use a room temperature chemical reaction resulting when components in the right proportion are brought together. In no bake molding the sand, resin and catalyst are mixed in a continuous mixer and the mixture is delivered right into the flask. Vibration is sometimes used to compact the sand. The mixer is controlled by the operator to deliver sand when needed.

Compaction in the green sand process can either be by hand or by using machinery. Jolt-squeeze molding is a common manual process used to make molds. This process uses a molding machine that both jolts and squeezes the sand onto the pattern plates.

a. Jolting

Jolting is a process where the pattern plate is assembled to a flask and is filled with green sand. This assembly is then lifted and then dropped, providing the jolting action that helps to compact the sand around the pattern plate.

b. Squeezing

Squeezing is a process where the pattern plate is again assembled to a flask and filled with green sand. The assembly is then squeezed either by hydraulic or pneumatic pressure.

c. Jolting/Squeezing

Both jolting and squeezing are combined into a jolt-squeeze machine. This helps to give good uniform sand compaction properties to the mold.

The cope and drag portions of the mold are created using these processes. The necessary cores are then placed into the cope or drag and the two halves of the mold are then assembled together.

Once the mold is finished, metal is poured into the mold and allowed to cool. And once the metal has cooled sufficiently the mold then goes through shakeout to remove and possibly reclaim the sand. The gating system is trimmed off, the casting cleaned up and the final product is ready for shipment to the customer.

The process shown here involves a lot of hand operations and produces horizontally parted molds. This process is suited for low to medium production volumes. Higher volume parts are produced on automatic molding machines. Molds produced by these machines may be either horizontal or vertical. The use of automatic molding machines lowers the labor required and increases the production rate.
Shell Molding

Shell molding is a variant of the sand molding process and uses a heat activated resin to bind the sand together similar to cold box or no bake molding. Although shell molding produces a mold with much less sand and resin used. Dimensional control and surface finish are improved with shell molding

In shell molding a pattern for the cope and drag are still utilized. Metal patterns are heated to a temperature around 450°F which is required to cure the resin binder. The patterns are assembled to a dump box which contains the resin coated and uncured sand. The dump box is tipped allowing the sand to flow onto the hot surface of the pattern and held there until a desired shell thickness is created. At which time the dump box is tipped back to its resting position and any uncured sand flows off of the pattern surface and back into the dump box.

This cured mold shell is stripped from the pattern plate and the cope and drag shells, as well as any cores, are then glued, clamped or clipped together for pouring.
Lost Foam Casting

The lost foam casting method uses an expanded polystyrene (EPS) foam pattern that is expendable. For each casting that is poured an EPS foam pattern is burned up.

The process starts out by creating a foam tool from which foam pieces are made. The casting design can have undercuts, minimal draft, anything that can be placed into the foam tool. Also, the final foam pattern can be made from several pieces of EPS foam that are glued together allowing design flexibility not possible in other casting processes. If the part is small, a tree of multiple foams can be glued together. This final foam piece will also have a gating system attached to it for pouring.

After the foam is complete, it is coated in a refractory wash, placed into a large flask, where dry, loose sand is poured around the foam while the flask is vibrated. The vibration effectively compacts the sand around the foam and helps to fill any difficult to fill areas.

The molten metal is poured into the flask instantly vaporizing the foam upon contact and replacing the volume it once occupied.

The solidified casting is removed from the flask after cooling and trimmed from its gating system. Lost foam castings exhibit a characteristic surface finish of the expanded beads and very little if any parting line flashing.

Lost Foam Casting Process

- Create Foam Pattern
- Assemble Foam Tree
- Refractory Coat Foam Tree
- Place Foam Tree into Flask
- Fill Flask With Sand And Vibrate Flask
- Pour Metal Into Flask
- Dump Sand From Flask and Remove Cast Tree From Flask
- Removing Gating And Clean Part

Figure 8 - The Lost Foam Casting Process
# Cast Materials

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<td>Elongation</td>
<td>33</td>
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<td>Hardness</td>
<td>33</td>
</tr>
<tr>
<td>Weight</td>
<td>33</td>
</tr>
<tr>
<td>Weldability</td>
<td>33</td>
</tr>
<tr>
<td>Machinability</td>
<td>34</td>
</tr>
<tr>
<td>Heat Treatability</td>
<td>34</td>
</tr>
<tr>
<td>Material Cost</td>
<td>34</td>
</tr>
</tbody>
</table>
The choice of a metal alloy used is as critical to a successful casting as the actual design itself. The part application and strength requirements will determine whether a ferrous (iron base) or non-ferrous alloy is chosen. Non-ferrous alloys would include Aluminum, Magnesium, Copper, Lead, and Nickel base alloys.

Every alloy will have a specific set of physical properties and the alloy choice will depend on the application requirements. If a part will be used in a salt water environment, corrosion resistance of the alloy will be important. If fatigue life is important, the mechanical properties of the material will be of the highest concern.

**Ferrous Alloys**

The family of ferrous alloys are composed primarily of iron (Fe) and carbon (C). The ferrous family is also broken into two materials, iron and steel.

The amount of carbon determines whether a material is a steel or an iron. Any iron based material with the carbon content above 2% (and up to ~4%) is considered an iron. Anything with the carbon content below 2% is considered a steel.

![Iron-carbon phase diagram](image-url)

*Figure 9 - Iron-carbon phase diagram*
There are many different kinds of cast iron that are being poured today. The mechanical properties of these irons are controlled by chemical composition and to a lesser extent cooling rate.

Iron can contain up to 3.5% of silicon (Si) and may also contain trace elements of manganese (Mn), sulfur (S), and phosphorous (P).

**Gray Iron**

Gray iron is characterized by a flake graphite structure in a matrix of ferrite and pearlite. The chemistry of the iron is modified to obtain the grade of gray iron desired.

Foundry processes are critical to the successful formation of the material microstructure. For example if an iron is cooled too quickly, white iron will form, which contains carbon in the form of cementite (iron carbide). This structure is very hard and difficult to machine. Replacing sharp corners on the casting with a suitable radius often eliminates the white iron or chill in the castings.

The size, shape, amount and distribution of the graphite flakes in gray iron helps determine the mechanical properties. Irons with a high percentage of ferrite in the matrix will be soft and easily machined but possess a lower tensile strength. Irons with a high percentage of pearlite will be harder, exhibit higher wear resistance and tensile strength. Figure 10 shows a polished sample with the dark lines being the graphite flakes within the iron matrix. Figure 11 shows the graphite structure after the iron has been removed. Note in Figure 11, the three dimensional interaction between the graphite flakes that Figure 10 may not convey.

The physical and mechanical properties of gray iron are characterized by:

1. Good compressive strength.
2. Good machinability.
3. Good vibration damping capacity.
4. Poor performance in a dynamic load application.
5. A lower modulus of elasticity than steel.
6. The ability to evenly disperse heat throughout its volume.

Grey iron is used in applications that
Ductile Iron (Carbon Content 2-4%)

Take advantage of its compressive strength and vibration damping capacity. It can be readily found in engine blocks, pump housings and valve bodies.

**Ductile Iron**

Ductile iron, also called nodular iron or spheroidal graphite (SG) iron, is characterized by the presence of graphite in a spherical form within the iron matrix, Figure's 12 and 14.

The addition of either magnesium (Mg) or cerium (Ce) creates nucleation points from which the graphite nodules form. Irons containing these nodules are much stronger and have better ductility than a conventional gray iron. The mechanical properties of a ductile iron are determined by the size and shape of the graphite nodules along with the composition of the matrix structure.

<table>
<thead>
<tr>
<th>Ductile Iron ASTM A536-84</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength (ksi)</td>
<td>Yield Strength (ksi)</td>
<td>Elongation (%)</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>40</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>65</td>
<td>45</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>55</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>70</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>90</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 12 - Ductile iron microstructure**

**Figure 13 - Ductile Iron Tensile Strength vs. Elongation**

**Figure 14 - Ductile iron microstructure**
Austempered Ductile Iron

The physical and mechanical properties of ductile iron are characterized by:

1. Good tensile and yield strength.
2. Greatly improved ductility over gray iron.
3. Improved fatigue strength over gray iron.
4. Good machinability
5. A lower modulus of elasticity than steel

There are various grades of ductile iron available. Table 1 displays some of the more common grades used. Also Figure 15 displays a chart showing tensile strength vs. material elongation values for these grades.

Ductile iron is used in a variety of applications. Some of the more common uses being, ductile iron pipe, automotive and agricultural equipment parts. It’s specifically useful in applications that require higher strength than grey iron or aluminum but may not require the strength or toughness of a steel.

Austempered Ductile Iron (ADI)

Austempered ductile iron is a heat treated ductile iron material that has higher tensile strength properties than a standard ductile iron.

Regular ductile iron consists of nodules of carbon surrounded by a ferrite pearlite matrix. ADI, is a ductile iron material that is heat treated and has had its microstructure transformed into an acicular ferrite (needle shaped) by quenching high carbon austenite in a molten salt bath.

The heat treatment consists of holding the material in a 1500-1750 °F furnace for a period of time until a carbon saturated austenitic matrix is formed. The material is then rapidly cooled to 450-750 °F and soaked at this temperature to form the microstructure required. There are six standard ASTM grades available listed in Table 2.

| Austempered Ductile Iron ASTM 897-06 |
|-----------------|-----------------|-----------------|
| Tensile Strength (Mpa) | Yield Strength (Mpa) | Elongation (%) |
| 750 | 500 | 11 |
| 900 | 550 | 9 |
| 1050 | 750 | 7 |
| 1200 | 850 | 4 |
| 1400 | 1100 | 2 |
| 1600 | 1300 | 1 |

ADI is utilized in numerous applications from the automotive industry to the agricultural equipment industry. Along with improved strength, ADI will have improved wear properties. Although machinability decreases with increasing strength levels, ADI has been used in applications such as crankshafts, bucket teeth and sprockets.
Cast Steels (Carbon Content <2%)

Cast Steels
There are many types of carbon and alloy steels used for castings. The choice of which will depend greatly on the application.

Cast steels can be broken into five generic groups, (Table 4), which depend on the carbon and alloy content.

Steels will also contain many different alloying elements within their chemical composition. Table 3 shows the various alloying elements and the effects that they have on the steel alloy. The more common elements are carbon, silicon (0.2%-2.5%), manganese (0.25% - 2.0%), and sulfur (max 0.05%).

Cast steels are often used when the impact properties or elongation of irons are insufficient for the application. Cast steels must also be specified if the part is to be welded. Cast steel alloys are formulated to exhibit certain material properties. This could range from enhancing mechanical properties like tensile strength and elongation, to improved machinability or hardenability.

A cast steel part is almost always heat treated after shakeout in order to get the required material properties for the part. Exceptions would include consumable wear castings. The mechanical properties that are achievable are greatly dependent on the alloy being heat treated.

<table>
<thead>
<tr>
<th>Element</th>
<th>Percentage</th>
<th>Primary Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manganese</td>
<td>0.25-2.0</td>
<td>Increases hardenability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Promotes and austenitic structure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Combines with sulfur to prevent brittleness</td>
</tr>
<tr>
<td>Sulfur</td>
<td>&lt;0.5</td>
<td>Contributes to machinability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduces weldability and ductility</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.3-5.0</td>
<td>Promotes an austenitic structure</td>
</tr>
<tr>
<td></td>
<td>12-20</td>
<td>Acts as a toughener</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increases hardenability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improves corrosion resistance</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.3-4.0</td>
<td>Increases hardenability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improves corrosion resistance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increases high-temperature strength</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Can combine with carbon to form wear resistant microconstituents</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>0.1-0.5</td>
<td>Increases hardenability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Promotes grain refinement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increases high-temperature strength</td>
</tr>
<tr>
<td>Vanadium</td>
<td>0.1-0.3</td>
<td>Increases strength while retaining ductility;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Promotes grain refinement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Will combine with carbon to form wear resistant microconstituents</td>
</tr>
<tr>
<td>Silicon</td>
<td>0.2-2.5</td>
<td>Removes oxygen in steel making</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improves toughness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increases hardenability</td>
</tr>
<tr>
<td>Copper</td>
<td>0.2-0.5</td>
<td>Improves corrosion resistance</td>
</tr>
<tr>
<td>Aluminum</td>
<td>&lt;2.0</td>
<td>Aids nitriding</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Restricts grain growth</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Removes oxygen in steel melting</td>
</tr>
</tbody>
</table>

Table 3 - Steel Alloying Elements

<table>
<thead>
<tr>
<th>Material</th>
<th>Alloying Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Carbon Steel</td>
<td>&lt; 0.2% Carbon</td>
</tr>
<tr>
<td>Medium Carbon Steel</td>
<td>0.2% - 0.5% Carbon</td>
</tr>
<tr>
<td>High Carbon Steel</td>
<td>&gt; 0.5% Carbon</td>
</tr>
<tr>
<td>Low Alloy Steel</td>
<td>&lt; 8% Alloy Content</td>
</tr>
<tr>
<td>High Alloy Steel</td>
<td>&gt; 8% Alloy Content</td>
</tr>
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</table>

Table 4 - General Alloying Content
**AISI Materials**

<table>
<thead>
<tr>
<th>Class</th>
<th>AISI Series</th>
<th>Major Constituents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Steels</td>
<td>10XX</td>
<td>Carbon steel</td>
</tr>
<tr>
<td></td>
<td>11XX</td>
<td>Resulfurized carbon steel</td>
</tr>
<tr>
<td>Alloy Steels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manganese</td>
<td>13XX</td>
<td>Manganese 1.75%</td>
</tr>
<tr>
<td></td>
<td>15XX</td>
<td>Manganese 1.00%</td>
</tr>
<tr>
<td>Nickel</td>
<td>23XX</td>
<td>Nickel 3.50%</td>
</tr>
<tr>
<td></td>
<td>25XX</td>
<td>Nickel 5.00%</td>
</tr>
<tr>
<td>Nickel-chromium</td>
<td>31XX</td>
<td>Nickel 1.25%, chromium 0.65 or 0.80%</td>
</tr>
<tr>
<td></td>
<td>33XX</td>
<td>Nickel 3.50%, chromium 1.55%</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>40XX</td>
<td>Molybdenum 0.25%</td>
</tr>
<tr>
<td></td>
<td>41XX</td>
<td>Chromium 0.95%, molybdenum 0.20%</td>
</tr>
<tr>
<td></td>
<td>43XX</td>
<td>Nickel 1.80%, chromium 0.50 or 0.80%, molybdenum 0.25%</td>
</tr>
<tr>
<td></td>
<td>46XX</td>
<td>Nickel 1.80%, molybdenum 0.25%</td>
</tr>
<tr>
<td></td>
<td>48XX</td>
<td>Nickel 3.50%, molybdenum 0.25%</td>
</tr>
<tr>
<td>Chromium</td>
<td>50XX</td>
<td>Chromium 0.30 or 0.60%</td>
</tr>
<tr>
<td></td>
<td>51XX</td>
<td>Chromium 0.80, 0.95 or 1.05%</td>
</tr>
<tr>
<td></td>
<td>5XXXX</td>
<td>Carbon 1.00%, chromium 0.50, 1.00 or 1.45%</td>
</tr>
<tr>
<td>Chromium-vanadium</td>
<td>61XX</td>
<td>Chromium 0.80 or 0.95%, vanadium 0.10 or 0.15% min</td>
</tr>
<tr>
<td>Multiple alloy</td>
<td>86XX</td>
<td>Nickel 0.55%, chromium 0.50%, molybdenum 0.20%</td>
</tr>
<tr>
<td></td>
<td>87XX</td>
<td>Nickel 0.55%, chromium 0.50%, molybdenum 0.25%</td>
</tr>
<tr>
<td></td>
<td>92XX</td>
<td>Manganese 0.85%, silicon 2.00%</td>
</tr>
<tr>
<td></td>
<td>93XX</td>
<td>Nickel 3.25%, chromium 1.20%, molybdenum 0.12%</td>
</tr>
<tr>
<td></td>
<td>94XX</td>
<td>Manganese 1.00%, nickel 0.45%, chromium 0.40%, molybdenum 0.12%</td>
</tr>
<tr>
<td></td>
<td>97XX</td>
<td>Nickel 0.55%, chromium 0.17%, molybdenum 0.20%</td>
</tr>
<tr>
<td></td>
<td>98XX</td>
<td>Nickel 1.00%, chromium 0.80%, molybdenum 0.25%</td>
</tr>
</tbody>
</table>

The more common heat treat processes are:

1. **Anneal** – provides a soft low strength structure with maximum ductility
2. **Normalize** – provides a medium strength and hardness with improved ductility
3. **Quench and Temper** – Provides the maximum strength levels with good ductility and wear resistance.

AISI materials, shown in Table 5, are common steel materials that are widely specified in wrought plate and bar product. Because of the extensive use of these materials, cast equivalents are always sought after. When looking for a cast material from a global source, a large number of the AISI materials can be found in a suitable cast form.
Care must be taken to specify the material properties required of the alloy being poured. For example, specifying a 1020 steel casting, that may have been converted from a weldment made out of 1020 plate could result in a cast 1020 material that has different elongation and yield values than the plate steel. There are standards that govern the material properties of the plate, but there may not be for the AISI cast material. It is pertinent to communicate both the material properties required and intended application for a steel casting to your casting manufacturer.
AISI Materials

Steel materials can also exhibit different material properties depending on the heat treatment. Figure 15 shows a plot of tensile strength vs. elongation of a few alloys. One thing to note is the difference in material properties between the identical alloys that have different heat treatments. AISI 4140 is used as an example here because of its common use as a highly heat treatable steel alloy. The trend shown, diminishing elongation with increasing tensile strength, is common across all steel materials.
Material Selection

One of the most important considerations when sourcing a casting is the material selection. Many factors determine what material will be used for the casting as shown in Figure 16. The mechanical properties, tensile strength, yield strength, elongation and hardness, play a major role in the selection of a material for an application. Although other properties, such as material weight, cost, machinability and hardenability will play a role in the selection of a material.

1. Material Properties

As discussed in previous chapters, a cast material will contain various elements, with each one playing a role in the mechanical properties of the material. This composition will define the achievable range of the mechanical properties of a cast material. The four mechanical properties that are most commonly defined are the tensile strength, yield strength, elongation and hardness.
**Mechanical Properties**

**Elongation** - Elongation is the amount of permanent deflection of a material as it is stressed to failure. This is expressed in a percentage of the materials original gage length.

**Hardness** - Hardness is a measure of the resistance of a material to deform. This is measured by methods such as Brinell, Rockwell and Vickers. Hardness is typically proportional to the yield and tensile strength of a material.

2. **Weight**
The density of a material, or the weight of the part, will also play a role in the material chosen. Aluminum is usually the material of choice from a weight standpoint. Although because of the differences in the yield strength of steel vs. aluminum, it is possible in certain applications for the weight of a steel design to compete with an aluminum design.

3. **Weldability**
Certain applications will require that a part be welded. Steel and aluminum materials can be welded.

In the case of steel materials, the carbon content will determine the weldability of the material. The higher the carbon content the more brittle a weld will become after it cools. Typically a material that has a carbon content at or above 0.30% may require a preheat on the parts.
Machinability, Cost

being welded and a post heat on the weld itself.

An alloy steel can be welded but a different approach is taken because some alloys will have a low carbon content but will contain other elements that will create a brittle weld. A carbon equivalency calculation, Figure 18, should be performed on the alloy to determine the weldability of the alloy.

Carbon Equivalency = 
\[ C + (Mn + Si)/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15 \]

Figure 18 - AWS D1.1/D1.1M:2002 Carbon Equivalency Calculation

4. Machinability

When selecting a material the machinability of the alloy may need to be considered. Sometimes a casting may need a free machining steel, such as 12L14, in order to help with tight tolerated features or improved productivity. See Table 3 for alloying elements that improve machinability.

5. Heat Treatability

The selection of a material that will need a heat treatment is dependent on the hardness and heat treatment required.

In the case of a low carbon steel such as a 1020, because of its low alloy and carbon content, it does not lend itself well to induction hardening but it is a good candidate for case hardening. 4140 on the other hand is a good candidate for induction hardening or through hardening.

6. Material Cost

The cost of materials will always affect a casting design. The use of the lowest cost material for the application is essential for a financially successful project.

Just placing materials in order from highest to lowest cost per kilogram, it would look like, Aluminum, Steel, then Iron. Although Aluminum is the highest cost per kilogram, it may be justified, because of Aluminum’s low density, from a weight savings potential. As well when you have a choice between using steel or ductile iron in a casting design, the material properties of a steel may allow for a thinner section in areas and thus a lower cost part.

When choosing a material based on cost it will be design dependent. Each material may dictate a different casting process and that casting process, as well as the material properties, will drive the part design.

As a casting is being developed and cost estimates are being tabulated, it’s good to keep in mind that a material change can drive design changes that may increase or decrease costs.
Casting Quality

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Introduction to Casting Quality

Introduction
Castings are often purchased to specifications originating from organizations such as the American Society for Testing Materials (ASTM), American Society of Mechanical Engineers (ASME), Society of Automotive Engineers (SAE), American Iron and Steel Institute (AISI), and International Organization for Standardization (ISO). Purchasers of castings may require additional specifications for specialized applications.

Some common requirements of a casting may include evaluation of:

1. Chemical Composition
2. Mechanical Properties
3. Dimensional Tolerances
4. Surface Roughness and Integrity
5. Internal Soundness
6. Nodule and Flake shape and size (for gray and ductile irons)

Chemical Composition
Steel castings are commonly ordered to mechanical property specifications. Additional requirements may include heat or corrosion resistance. The chemical composition of the material is specified in order to produce a material that fits the application it will be used in.

In the example of a steel, if the application is non structural and not of a critical nature, the composition of the material may not be controlled as tightly as if it were an application that had a low factor of safety and a very tightly controlled mechanical property specification.

If an ASTM specification is being used, the composition may be fairly open, but the mechanical properties are controlled tightly.

Just as well, an ASTM specification may require chemical composition to be verified but not mention the mechanical properties. It is best when using external specifications, to verify that the material the specification defines will actually fit the application.

Mechanical Properties
It is common practice to verify the mechanical properties of a material. Some of the mechanical properties that are inspected are tensile properties, bend properties, impact properties, fatigue properties and hardness. These properties are described in detail below.

Tensile Properties
It’s common practice to verify the tensile properties of a cast material. The properties tested may include ultimate tensile strength, yield strength, elongation and reduction of area. The material tested is taken from a representative sample, test bar of the same metal used to cast the parts.

Bend Properties
Bend properties of a cast material are typically not measured. This is more commonly applied to weld qualification tests. Measuring the bend properties of a material is performed by taking a bar of given dimensions, bending it to a specified angle around a pin of given radius and monitoring for cracks on the surface of the material.

Impact Properties
An impact property or toughness is determined by measuring the amount of energy needed to fracture a sample. The Charpy V-notch test is a common test used to do this. Typically, the better the ductility and strength of a material, the better the toughness.
Fatigue Properties
Fatigue testing consists of stressing a material for a number of cycles and determining the number of cycles needed to cause failure.

An S-N curve can be developed for the material, the S representing stress and the N representing the number of cycles. Also determined from this testing is the endurance limit of the material.

Fatigue testing can be used to qualify designs, processes and materials but rarely is this done by regular heat lot evaluation.

Hardness
Hardness is a measure of the resistance of the material to indentation. This is measured by methods such as Brinell, Vickers and Rockwell. Hardness tests are often used to verify the heat treatment and physical properties of the cast steel for individual furnace loads.

Dimensional Tolerances
A casting's dimensional tolerance is developed from various factors.

The tolerance of a raw casting is largely defined by the type of process used. An investment cast part will yield significantly better dimensional capability from a sand cast part. A sand cast part that has a sand mold compacted by an automated machine will yield a better dimensional capability than a sand mold created by hand.

There is some tolerance used up in the creation of the pattern as well. The pattern is built expecting a certain amount of contraction from the pattern to the final part. The correct amount of adjustment that is made to the pattern for the alloy being poured can be uncertain due to the part geometry and this can drive to a larger tolerance on the final part. If certain dimensions are critical, a small amount of capability castings, using the production process, can be poured before regular production begins.

The size and the weight of the part will determine the tolerance required on spe-
Casting Defects

Specific dimensions. Table 6 shows the casting tolerances (CT) achievable for several materials and mold making processes. Tolerance grades will differ for different casting processes. The tolerance table shows the different tolerances required for various dimensions.

In a complex mold, there may be 4 or more components in the mold that need to be assembled before pouring. This assembly of the mold will also determine the dimensional variation of the parts. Critical dimensions of the parts should be designed so that they are molded in as few components as possible.

**Flatness**

<table>
<thead>
<tr>
<th>Casting Length</th>
<th>As Cast</th>
<th>Mechanically Straightened</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&quot;</td>
<td>0.20mm</td>
<td>0.10mm</td>
</tr>
<tr>
<td>2&quot;</td>
<td>0.38mm</td>
<td>0.15mm</td>
</tr>
<tr>
<td>4&quot;</td>
<td>0.64mm</td>
<td>0.25mm</td>
</tr>
<tr>
<td>6&quot;</td>
<td>0.76mm</td>
<td>0.38mm</td>
</tr>
</tbody>
</table>

Table 7 - Investment cast flatness tolerance

Cleaning and heat treating will also affect a parts dimensions. Heat treating specifically will affect flatness and straightness of a casting. Table 7 shows the achievable flatness for an investment cast part, with and without mechanical straightening.

**Surface Finish**

As shown in Table 8 the surface finish of a casting will vary greatly depending on the process being used. An investment cast part will yield about a 125 µinch RMS surface, a die cast part about a 64 µinch RMS surface while a sand casting will be around 500 µinch RMS.

The surface finish will be modified in areas where a gate or riser has been removed. This can be a broken area where the gate was snapped off or a ground/cut surface where the gate was removed.

The surface finish in all casting processes can be modified through out the part by shot or bead blasting if needed but adds cost to the final part.

**Internal Soundness**

The internal soundness of a casting can be important in some applications. But keep in mind, it is very difficult to cast a defect free casting. Determination of the acceptable defect level in a casting is important and over specification of the defect level will lead to higher scrap rates and higher casting costs.

There are many different casting defects that can occur. With the three most com-
Porosity & Inclusions

Porosity: Porosity is a void in the casting that is characterized by smooth interior walls that are shiny or in the case of iron, are covered with a thin layer of graphite. These voids can appear in one large cavity or several small cavities dispersed throughout the casting.

Possible Causes:
1. Mechanical Gas Entrapment
   - A large amount of mold or core gas with insufficient evacuation from the mold cavity
   - Entrainment of air due to turbulence in the gating system

2. Metallurgical Origin
   - Excessive gas content in melt
   - In the case of steel and irons, formation of carbon monoxide by the reaction of carbon with oxygen present in the melt.

Remedies
- Include vents in the mold cavity to allow the escape of air
- Review gating design for turbulent areas
- Ensure that the sprue is kept full during pouring
- Reduce pouring height
- For steel, deoxidize the melt adequately
- For iron, avoid using rusty charge material which will introduce oxides into the melt
- For non-ferrous alloys, avoid excessive melt temperatures and use care in degassing.

Inclusions:

Inclusions are a piece of foreign material in the cast part. An inclusion can be a metallic, intermetallic or nonmetallic piece of material in the metal matrix.

Possible Causes:
1. Metallic Inclusions
   - Charge materials which have not been completely dissolved in the melt.
   - Exposed core wires or rods.

2. Intermetallic Inclusions
   - Combinations formed between the melt material and a metallic impurity

3. Non-metallic Inclusions
   - Loose sand in the mold
   - Flakes of refractory coating breaking loose from the mold

Remedies:
- Avoid entrainment of slag and dross from the furnace while filling the ladle
- Use siphon, teapot and bottom pour ladles
- Keep pouring basins and sprue filled during pouring
- Use strainer cores or filters
- Create slag traps in casting gating
Shrinkage

Definition: Is a vacancy typically internal to the casting that is caused by a molten island of material that does not have enough feed metal to supply it. Shrinkage cavities are characterized by a rough, dendritic, interior surface.

Possible Causes:
- Volume contraction of the metal, either from liquid contraction of the melt or from contraction during phase change from liquid to solid
- Insufficient feed metal in defect areas. Gating, feeding system and part design creates locally hot areas within the casting that are not fed well.

Remedies
- Avoid heavy isolated casting sections that are difficult to feed.
- Design the part with a progressive change in casting thickness
- Design the gating and feeding system to provide for directional solidification back to the risers.
- For gray and ductile irons, increase carbon and silicon content as allowed, to decrease volumetric contraction of the metal during solidification
- Limit the pouring temperature so that the liquid contraction is minimized.

Inspection Methods
There are various test methods that may be employed to evaluate the soundness of a casting. These can be destructive or nondestructive tests. The more common tests employed are magnetic particle inspection, radiography and a method of destructive testing where a part is milled in small layers to reveal defects.

These inspection methods are employed in some way on a majority of castings. Although care must be taken when specifying the defect severity levels for each method. Over specifying will always lead to a more expensive part than what is needed.

All materials that are specified have certain minimum inspection criteria, typically involving chemical analysis and mechanical property verification.

Whether to specify added testing can be dependent on some of the variables listed below

1. The casting has a proven history with little to no issues
2. The design uses large safety factors
3. The application is not critical
4. The part can be cast with little trouble

Extra testing may be required if:

1. The design is new and untested
2. There are low safety factors used in the design
Magnetic Particle Inspection
This is a non-destructive test used to detect surface or near-surface defects in ferrous materials only.

An externally applied magnetic field or rectified AC current is passed through the material. A liquid that contains either magnetic iron oxide or finely divided iron particles is applied to the part. These magnetic particles are attracted to the area of the defect and display the defect for an operator.

Experience is needed for this process in order to interpret the results and ensure that magnetic anomalies are not read as defects.

The defects that are found in the tested part are compared to reference photographs to determine the severity level of the defect.

Radiography
Radiography is used if internal inspection of a casting is needed. Internal defects such as shrinkage voids, porosity, and inclusions can be found using this method.

Figure 23 - Destructive testing
Similar to magnetic particle inspection, the defects are compared to reference radiographs to determine the severity level of the defect. Severity levels range from 1—5, one being small, five being large.

There are limitations here that are described shown in Figure 22. There will be areas in a casting that an x-ray cannot be obtained. If these areas are critical another method of inspection may need to be employed.

**Destructive Testing**

Another method of casting defect inspection, which is more labor intensive, is a destructive test. This method uses a mill to cut away layer by layer in the part and reveal the defects present in the part.

This method will reveal large defects but Level 1 defects and metallic inclusions that are revealed in a radiograph may not be seen using this method.

Figures 23 and 24 shows a comparison between two methods of destructive testing. Figure 23 uses a “bread loaf” cutting method. This method is typically used when inspecting a large part that does not have tight control on the castings defect level.

Figure 24 shows a method used for defect inspection of a majority of parts. Figure 24 is a localized inspection for a large shrinkage cavity, although this can be performed on a whole part.

Destructive testing gives a very good three dimensional view of the void, whereas a radiograph will only be a two dimensional representation of the defect. This method of testing is also a quick and easy check where radiographic inspection may not be readily available.
Casting Design Guidelines

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Introduction to Design Guidelines

Introduction
When designing a casting it’s important to consider the tolerancing capabilities (both dimensional and geometric) of the casting process being used as well as any draft and required minimum radii and fillets.

When undertaking a casting design the casting designer has to limit the shrinkage defects that can form in the casting. A gating and risering system is used to fill the part with molten metal and control the defect level in the finished casting. Although, as you will see in this section, the casting design will determine the amount of feed metal needed in order to maintain a specified defect quality level.

Good detailed prints are an absolute necessity in designing castings. The print is a communication tool that describes what the designer requires in the final product.

Draft Requirements
Most castings require draft on surfaces to help with the extraction of the pattern from the mold. The amount of draft required is dependent on the casting process used as well as the length of the feature being drafted.

Draft will typically start from the parting line and extend to the end of the feature. In the case of a sand mold, Cores may be used if the casting design requires zero or negative draft angles.

<table>
<thead>
<tr>
<th>Casting Type</th>
<th>Draft Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Die Casting</td>
<td>1°-2°</td>
</tr>
<tr>
<td>Ceramic Investment Cast</td>
<td>0°-3°</td>
</tr>
<tr>
<td>Silica Investment Cast</td>
<td>0°-3°</td>
</tr>
<tr>
<td>Shell Mold</td>
<td>2°-5°</td>
</tr>
<tr>
<td>Sand Casting</td>
<td>3°-5°</td>
</tr>
<tr>
<td>Lost Foam Casting</td>
<td>1°-2°</td>
</tr>
</tbody>
</table>

Table 9 - Typical Draft Angles

Cores are a separate part of the casting mold that are typically created from a chemically bonded sand and placed into one half of the mold before both the cope and drag are assembled. Cores typically for the internal surfaces of the castings.

Figure 25 - Draft for sand casting

Figure 25 illustrates the reason draft is required on all sand cast parts. Draft allows the pattern to be cleanly removed from the sand before assembly and pouring. Without it the sand mold will be destroyed when the pattern is removed.

Investment castings commonly have greater design flexibility. They are produced from wax patterns that are created in metal molds. Zero draft and negative draft angles are achievable

Undercuts are achievable by either placing an insert in the tool that can be moved prior to ejecting the wax part from the tool or by creating two separate parts and assembling them together prior to coating. Figures 26 and 28 show an example of as-
Casting Shrinkage

Semblng two separately molded pieces together.

Lost foam castings will require draft in areas for easy extraction of the foam from the tool, but undercuts can be created by either pulls placed in the tool or by creating two separate foam pieces and gluing them together.

Shrinkage

All castings will shrink as the metal transitions from a liquid state to a solid state. As a casting cools there are three phases of shrinkage, liquid shrinkage, solidification shrinkage and solid shrinkage.

Liquid shrinkage is where the melt cools and as it is cooling the melt is changing volume in its liquid form. Solidification shrinkage is an effect of the phase change from liquid to solid. This is just the same as water changing phase from liquid to ice. Solid shrinkage is a stage of shrinkage where the temperature of the solidified casting is decreasing causing the casting volume to decrease also.

The liquid shrinkage and solidification shrinkage are the primary cause of shrinkage defects in castings. A parts design will determine the likelihood that a shrinkage defect will occur. Gating and risering are

Figure 27 - Three phases of shrinkage

Figure 28 - Wax with insert
Controlling Casting Shrinkage

employed in such a way as to reduce the amount of shrinkage or move it into a non-critical area of the casting.

The third phase, solid shrinkage, occurs after the metal has solidified. This shrinkage is accounted for in the pattern sizing.

Controlling Casting Shrinkage

In a casting, a shrinkage void occurs because an area internal to the casting has remained molten. If there is not a sufficient amount of molten metal to feed the shrinkage, a void may occur as the material solidifies forming a shrinkage cavity.

Figure 29 shows a simple representation of a part that would possibly have a shrinkage cavity. In this case the feed metal coming from the sprue area is cut off due to solidification. This effect leaves an area in the middle of the plate that will likely have a shrinkage cavity.

One way to fix this problem is to add padding to the area of the casting that is experiencing shrinkage. In Figure 30, you can see that the part now has some material added that promotes directional solidification back to the molten sprue or riser. As this casting cools there is still a molten path open that will feed the liquid and solidification shrinkage, giving you a part with minimal shrinkage defects.

Another method of reducing the shrinkage cavity is adding a riser, shown in Figure 31. This is typically done by the foundry engineer and not necessarily by the casting designer. Here the riser is added near the shrinkage defect. The defect still occurs but will end up in the riser, which is removed after the casting cools. Risers require additional metal for the casting process, removal and additional finishing. All of which tend to increases the cost of the finished casting.

The probability of shrinkage is increased as the modulus of the section increases. The modulus is defined by the volume of
Junction Design

the section divided by the surface area. Areas with higher modulus are the last to solidify and must be risered.

Fillets and Radii
Generous rounds and fillets are trademarks of a good casting design. They improve the appearance of a casting as well as help to distribute strains and reduce cast stresses present in the part.

As well, generous fillets will help with the pour of the part. As a casting is poured, the melt velocity and geometry of the part may cause turbulence to occur in certain areas. This turbulence encourages the melt to mix with the air in the casting cavity and form oxide inclusions. Having adequate corner fillets will help the molten metal to flow and fill the cavity adequately with a reduced chance of turbulent flow.

In the case of a junction design as shown in Figure 32, adding a fillet at the base of the rib will help transition the flow of metal and reduce the chance of turbulence in this area. A simple rule of thumb as far as fillet sizing for this junction is to make the fillet radius equal to the rib thickness, up to a 1" fillet. Sharp interior corners allow the molding sand to superheat causing rough surfaces. Sharp exterior corners may cause hard spots and chill in iron castings.

Junction Design
The design of a junction in a casting can cause shrinkage cavities to form. In Figure 33 below, there are two junctions shown, a “T” and “L” junction. The thickness of the casting here is consistent, although at the center of the junction, there is an area that may form shrinkage porosity.

For the “T” junction, it is typical to use the Fair design, in most alloys and definitely in irons you will be safe to use this design. Although if you are casting in an alloy that has a high amount of solidification shrinkage you may need to reduce the molten area by adding a divot as shown.

With the “L” junction, the Fair design is common also, although there is greater risk of a shrinkage defect in this design. In materials with low solidification shrinkage, such as ductile and gray iron, you will most...
Print Requirements

likely not have an issue. In high alloy mate-
rials you will experience a higher risk of
shrinkage defects in the Fair design, over
the Good.

As well in “L” junction, there is usually lit-
tle issue with having a generous radius on
the external corner.

Machining and Casting Drawings

Casting drawings will include information
about the casting geometry (size, shape,
draft, radii, etc..) The casting drawing will
also contain the acceptable tolerance level,
defect level, and surface finish. As well as
any inspection requirements, radiography,
magnetic particle inspection, destructive
testing. Material will be defined on the
print with possibly the mechanical proper-
ties of the material. Geometric dimension-
ing and tolerancing may also come into
play on a casting design.

All of this, when included on a print,
helps convey the expectation of the part to
the foundry. Make sure to display what is
critical to your part on the print. If you
need to have good elongation in your ma-
terial, this may require a specific heat treat
to the part. You may need to maintain a
consistent surface finish in an area and this
may define, for the foundry, areas that gating
and risering can and cannot be.

A casting can also have the part number,
heat lot and foundry code cast into the
part. Specification of the location and size
of this lettering is required. If raised letter-
ing causes interference, the lettering can
be cast in a recessed pad.

A machined casting will have dimensions
for the machined features as well as di-
mensions relating the machined features
to the cast features. The machining print
may include a note on corner breaks re-
quired, surface finish callouts for the ma-
chined surfaces, geometric tolerances, etc.

Foundries typically prefer two drawings,
one for the casting and one for the finished
machined part. The casting print will in-
clude the amount of finished stock re-
quired. 3mm or 0.125” of machine stock is
typical.

Figure 34 - Datum Points
When geometric tolerancing is used on a casting print or machined casting print, it is always good practice to establish datum points at specific locations on a cast surface for the various datum planes. With the surface inconsistencies, this practice allows consistent inspection and layout at the foundry, machinist, outside inspection lab and customer. All tooling can be built to reference these datum points and it will go a long way to help with any dimensional issues that may come up with a machined casting.
Weldment to Casting Conversion

Introduction
Casting designs allow the designer more freedom in the part design than a weldment. The design can be very fluid and conform to almost any shape. As well castings generally have equivalent fatigue properties when compared to a fabricated design.

Design Freedoms
One of the benefits of a cast design is the ability to have tapered sections, where as in a weldment you may have to use a certain thickness of plate that may only be needed for one high stress area in the design. Casting designs can have material placed where it is needed and removed from where it is not needed. This allows for a more efficient and cost effective design. Castings also exhibit unidirectional strength compared to differences in plate strengths due to rolling direction.

All weldment features can be cast into the design. Bosses can be cast into the part at bolting locations. In a weldment, these bosses would need to be fabricated and then welded on. Complicated sections can be easily recreated in a casting, in a weldment it is difficult and expensive to create a complex cross section. As well, if you are dealing with a part that flows fluid, a casting can be created that streamlines that fluid flow.

Because most castings undergo some sort of heat treatment, the internal stresses in a casting are typically lower than a weldment. Weldments also will have some distortion in the final part due to localized stresses at the weld areas.

Defining a Good Conversion Candidate
Any weldment can be converted to a casting but there are times where a weldment may be more economical. As you start looking at weldments and designing a cast equivalent, it is good to start with the weldments that take the most time to fabricate and may not make the best use of the plate material. As well, if there are any current issues with the weldment, such as fatigue failures, a casting may be a good candidate.

Design Considerations
Designers who are considering the conversion of a weldment to a casting should first consider the molding process required to obtain the desired geometry. Steel investment castings yield excellent material properties and greater design flexibility but may be priced higher than a comparable ductile iron sand casting because of the material cost.

Steel is typically the choice if:
1) Excellent material properties are required
2) The casting may experience impact loading
3) The casting needs to be weldable

A steel investment casting is the choice if:
1) There are many undercuts and zero draft areas required.
2) Good surface finish is required
3) Good dimensional control is required

An iron casting is typically the choice if:
1) Impact toughness of the material is not a concern
2) Surface finish is not a concern
3) The part is cost sensitive

Once the material and casting process has been determined it’s time to start looking at the weldment to see how a casting design would work within the design constraints.
All of the components in the weldment are manufactured separately.

The part is welded together for the final product.

A cast version of the weldment is proposed.

FEA is run on both the weldment and the casting to compare the strength of the design.

Figure 35 - Weldment conversion sample
Weldment to Casting Conversion

To start the design work first determine the functional features in the application. Ask the questions: Where does the casting attach to the application? What will need to be bolted or welded to the casting? These things will probably carry over from the weldment design to the casting design.

Once the functional features are identified, determine how these features can be connected by cast material. Some weldments use a boxed or tube section between the various features. This is not easily produced in either investment or sand casting. In this case the choice of an I-beam or C-section may be required.

If the weldment design is a flat plate already with a few bosses and gussets, a cast alternative is pretty easy to envision. Bosses and gussets can be easily cast into the design.

Once the basic geometry for the casting has been created the next step is to look at the design and determine a logical parting line for the design. A parting line on one plane is always easiest to tool and will result in a less expensive tooling charge. After the parting line is set the next step is to start adding in the necessary amount of draft for the casting process.

After the draft is applied the last step in the casting design is to add radii and fillets to all corners and edges. Typically a minimum of 3mm or 0.125” radii are required. Although smaller can be achieved, you will want to check with your metal caster to see what is achievable.

Once the casting design is complete the machined features can be added. One thing to be aware of here is that the cast features will have a larger tolerance on their size and location than the machined features. This needs to be taken into account in the casting design. In the case of a cast boss that is drilled, the boss should be sized such that with the cast tolerances the drilled hole will not create a thin wall on the boss.

The process of designing a cast alternative can be difficult in some cases and just looking at one part to convert may not be the best solution. It’s always a good idea to look at the system of parts and possibly combine features of multiple components into a single casting.