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Introduction

In this chapter, we will:

◊ Compare the die casting industry to other metal casting industries.
◊ Discuss a brief history of the process.
◊ Discuss the modern die casting industry and the trade association that leads it.

After completing this chapter, you will be able to:

◊ List the topics covered in this course.
◊ Identify the two major differences between die casting and other metal casting processes.
◊ List the three elements that form the basis for most die casting materials.
◊ List at least five services provided by the die casting trade association, NADCA.

The information presented in this chapter is of general interest and is background information for material presented in following chapters.

The following new terms are used in this chapter.

Metalcasting  The entire industry of pouring liquid metal into a mold for the purpose of achieving a desired shape.

Metalcasting

Metalcasting is an ancient industry. Its modern roots include:

◊ Sand casting
◊ Investment casting
◊ Lost foam casting
◊ Permanent mold casting
◊ Centrifugal casting
◊ Die casting
With the exception of die casting, the processes listed above are known as “foundry” processes.

Die casting is a particular variation of metalcasting where liquid metal is forced into a reusable steel mold, or die, very quickly with high pressures. Reusable steel tooling and the injection of liquid metal with high pressures differentiates die casting from the other metalcasting processes.

Sand casting, investment casting and lost foam casting processes all use gravity to fill the mold. After the mold is filled, it is destroyed to remove the casting. Mold making is as important a part of these processes as is making the casting.

◊ Metal flow is slow.
◊ Walls are much thicker than in die casting.
◊ The cycle time is longer than die casting because of the inability of the mold material to remove heat.

Permanent mold casting could be considered a cousin to die casting. In this process the mold is reused, not destroyed. The process uses gravity to fill the casting; so flow control is similar to sand casting.

◊ Metal flow is slow.
◊ Since the mold is steel, and has comparatively good thermal conductivity, the release agents used in this process are also insulators. This is necessary, to keep the casting from freezing prematurely, and to prevent filling.
◊ Machines for this process are smaller than die cast machines used for similar castings.

Centrifugal castings are frequently made by jewelers. This is the choice for low volume castings with a small amount of pressure.

The molds are placed around the circumference of a centrifuge. As the centrifuge spins, metal is poured in at the center and centrifugal force distributes the metal to the molds.

Die casting is a process involving the injection of molten metal at high pressures (as opposed to casting by gravity pressure).

History of Die Casting
Die casting is believed to have begun sometime during the middle of the 19th century. According to records, in 1849 Sturges patented the first manually operated machine for casting printing type.

Another 20 years passed before the process was extended to casting other shapes. The casting of printer’s type led to patents that eventually resulted in development of the linotype machine by Ottmar Mergenthaler.

The earliest commercial applications for die castings occurred in 1892 when parts were produced for phonographs and cash registers.

Mass production was further encouraged when the H.H. Franklin Company began die casting babitt alloy bearings for automobile connecting rods shortly after the turn of the century.
Various compositions of tin and lead were the first die casting alloys. Their importance and use declined, however, with the development of zinc alloys just prior to World War I. Magnesium and copper followed shortly thereafter.

During the 1930s, many of the alloys we know today had become available. Modern science and technology, metallurgical controls and research are making possible still further refinements resulting in new alloys with increased strength and stability.

Through the years, many significant technological improvements have been made to the basic die casting process:

◊ To die steels
◊ To die construction
◊ In casting capability
◊ In production capacity of the process

These improvements have been tremendously effective in expanding die casting applications into almost every known market.

**Modern Die Casting**

In 2015, there were approximately 375 die casters in North America, with sales of $7 billion. Die castings were produced from aluminum, copper, lead, magnesium and zinc alloys as well as various composite materials. The top three alloys are aluminum, zinc and magnesium.

◊ These castings are used in Cars, Machinery, Office equipment, Appliances, Sporting goods, Toys, and Many other applications.
Course Introduction

Die casting operations are divided into two major categories.

◊ “Captive” die caster. This is an operation that only produces die castings for their own use. General Motors is an example of a captive die caster. At the GM plant in Bedford, Indiana, transmission and engine die castings are produced for use in GM-manufactured automobiles and trucks.

◊ “Custom” die caster. Custom die casters produce castings for their customers’ use. For example, IBM Corporation, an original equipment manufacturer, or OEM, may contract with a custom die caster, such as Pace Industries, for the manufacture of an electronic housing. Pace would then manufacture the electronics housing for IBM to IBM’s specifications. Custom die casters typically only manufacture for other companies, not themselves.

Summary
Metalcasting is an old industry and its roots include five foundry processes in addition to die casting. Most of these processes use gravity to fill the casting, unlike die casting, which uses the injection of molten metal at high pressure.

◊ Die casting is believed to have begun in the 19th century for the casting of printing type. This led to the development of the linotype machine. Various metal compositions were used in the early years. These have been refined resulting in new alloys with increased strength and stability. Processes have also greatly improved.

◊ The top alloys used today are aluminum, zinc, and magnesium. These are used in a wide variety of items, including cars, sporting goods, and toys. These are typically produced by captive or custom die casting companies.

◊ NADCA, the North American Die Casting Association, is the trade association representing the industry. The mission is to be the worldwide leader of and resource for stimulating continuous improvement in the die casting industry.
Introduction
Why would a product designer choose a die casting over a component manufactured by another competing process?

What are the capabilities of a product made with the die casting?

During this session, we will answer those questions. We will also explore the length and breadth of die casting applications, and explain the unique characteristics and optimum die casting configuration.

After completing this chapter, you will be able to:
- List the advantages of using die castings.
- Identify die casting applications.
- List the characteristics of the optimum die casting configuration.
- Identify the components of the die casting shot.

The information presented in this chapter is of general interest and is background information for material presented in following chapters.

In the previous chapter you learned general information about the die casting industry in North America. In this chapter you will learn specific information about the die casting.

The following new terms are used in this chapter.
- **Die casting “shot”** Defined as a noun in this chapter, not a verb.
- **Sprue** Cone-shaped metal part of the shot that connects the nozzle and runner.
- **Overflows** Small pockets of metal around the perimeter of the part and also in openings.
- **Runner** The path the metal must flow through to get from the sprue or biscuit to the casting.

The Die Casting Advantage
Die casting produces components at high speed from a range of durable metal alloys while faithfully capturing the most intricate design details.

This capability makes it a prime production option for high volume production components. The ability to maintain close tolerances, often eliminating all machining, can make the process the optimum choice for lower-volume production as well.
Figure 2-1 - The large aluminum automotive transmission housing shown on the left is produced on a 3500 ton cold chamber die casting machine. The aluminum fills the complex die cavity in less than ½ second and a completely formed solidified casting is ejected from the die every two minutes. Transmission housings weigh up to 35 lb. In contrast, the small zinc line connector for a cook stove is produced on a much smaller machine. The zinc fills the cavity on the order of a few hundredths of a second and several castings are ejected every minute. The weight of each of these castings is 0.5 ounces.

Today, with the introduction of new, higher performing die casting alloys and new process technologies, many of the old design assumptions about process limitations have become obsolete.

◊ New specifications for dimensional control, draft and flatness have been issued. These specifications are reviewed and updated on a periodic basis.
◊ New process enhancements including vacuum technology, squeeze casting, semi-solid casting and thixotropic molding have been developed and have led to significantly reduced levels of porosity.

**Die Casting Process Advantages**

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<td>Modern process technology that insures consistent quality</td>
<td>Computer control of the significant process variables has led to consistent dimensional control and internal integrity. The process responds to statistical control and statistical problem solving techniques.</td>
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<td>Freedom to design intricate configurations</td>
<td>Design configuration is only limited to the designer’s imagination and the moldmaker’s ingenuity to build the casting die. A typical example of an intricate configuration is the automotive transmission valve body.</td>
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<td>Net-shape casting economies, even at lower volumes</td>
<td>Elimination of machining and secondary operations can make die casting competitive at low production volumes.</td>
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<td>Wide variety of available alloys and alloy properties</td>
<td>Recall that the typical metals are alloys of aluminum, magnesium and zinc. Small volumes of alloys made from copper and lead are also routinely die cast. Iron and titanium materials have also been die cast. Current alloy development includes the use of composite materials, aluminum and silicon carbide for example.</td>
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The rigidity, look and feel of metal

The perceived quality of a metal component is higher than that made from a non-metallic material. Rigidity is analogous to strength, and is based on the modulus of elasticity, and configuration. Good rigidity also reduces vibration.

Meets moderate to high strength performance

Die cast alloy strengths are above plastics and slightly below those of sheet steels.

Moderate to high impact and dent resistance

Selected alloys have very high-energy absorption capability.

Documented fatigue strength characteristics

Published values of fatigue strength are conservative. High density casting processes minimize defects, such as porosity, that initiate fatigue.

Excellent sound damping properties

Studies indicate zinc and ZA alloys are good at sound damping. Magnesium has demonstrated sound damping in drive train components.

Bearing properties that often eliminate separate bearings

ZA alloys have good bearing properties. Aluminum 390 alloy shows good wear resistance.

Inherent EMI shielding for electronic applications

High conductivity provides inherent shielding.

Pressure tightness for hydraulic and pneumatic components

Alloy selection, gating technology and vacuum systems greatly reduce trapped gases and shrinkage porosity.

High quality surface finishes for decorative applications

Good surface finish is relatively easy to achieve. A variety of surface treatments are easy to apply.

Meets criteria for serviceability and recyclability

Alloys are “green”, easily recycled. The aluminum alloys are usually produced from recycled materials. The die casting alloy recycling stream is based on a worldwide metal reclamation infrastructure that has been operative for more than 50 years.

The Optimum Die Casting Configuration

Before a die casting project is undertaken, the casting design should be evaluated in terms of manufacturability. In other words, can the casting be manufactured? Is the casting design optimum?

The optimum die casting configuration will:

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

The optimum casting configuration does not just happen. Engineers and designers must work together to make sure the casting design fulfills the product requirements and can be manufactured. To achieve both of these goals, the die casting must be designed with features that capitalize on the characteristics of the die casting process. The following six principles should be used in working toward and developing the optimum die casting configuration.
Wall thickness should be as consistent as possible

There are no hard and fast rules governing wall thickness and consistency. Inherent in the process is a wall section that possesses a dense fine-grained skin, 0.015-0.020 in. thick (0.4-0.5 mm). The material between the surface skins tends to be less dense and large grained as a result of a longer solidification time. This is where defects tend to congregate.

Die casters have demonstrated the capability of casting 0.06-0.07 in. (1.5-1.8 mm) thick aluminum walls over large surface areas. It is feasible to cast small areas as low as 0.04 in. (1 mm). Zinc alloys flow more readily, and can be cast to wall thickness as low as 0.03 in. (.75 mm) Magnesium alloys can be cast to wall thickness 0.035-0.045 in. (.89-1.14 mm)

Wall sections should be as uniform as possible. It is difficult to achieve uniform and rapid solidification of the alloy if the heat load varies from one location to another in the die. Thinner walls contribute a lesser heat load than heavier walls and will have a longer die life.
Intersections of walls, ribs and gussets should blend with transitions and generous radii

Generous radii, outside corners, and transitions promote metal flow and internal integrity. Radii and fillets also enhance structural integrity by reducing stress concentrations in the casting. Additionally, fillets reduce heat concentration in both the die and castings. Hot spots that result from sharp corners promote shrinkage voids in the casting. These hot spots also reduce die life at sharp corners in the die cavity steel.

Standard draft should be specified

Draft is highly desirable on surfaces parallel to the direction of die draw because it facilitates ejection by allowing the casting to release easily from the die surfaces. The NADCA Product Standards recommendations for minimum draft should be specified.

![Figure 2-3 - Example of draft specification.](image)

Sharp corners should be eliminated or minimized

If sharp corners are required, they readily are accommodated at parting lines and at the junctions of die components. Sharp corners should be broken with radii or chamfers.

Undercuts should be avoided

Undercuts should be avoided because they may require machining operations or additional die components, such as retractable core slides. Slides increase the cost of die fabrication and maintenance. They can also add to cycle time and manufacturing problems if they flash. If possible, the component should be redesigned to eliminate undercuts.
Dimensions with critical tolerances should relate to only one die half
Dimensional precision is greatest when the related features are in the same piece of cavity steel. Precision is reduced for relationships across the parting line or to moving components such as slides.

Other component features that capitalize on the die casting process are ribs. Low mass and high surface areas typically characterize ribs, in other words, thin walls. Judicious use of ribbing can aid die filling and strengthen the component. If heavy sections are present in a design, an attempt should be made to reduce the mass through thinner walls and rib reinforcement.

The Shot
The result of injecting metal into the die, i.e., making a shot (verb), is also called a shot (noun).
Overflows have several purposes

◊ Mostly they are used as a reservoir for the first metal to flow through the cavity. This metal gives up a lot of heat and may not be suitable to remain in the casting because it is too cold. The first metal through also contains oxides and lubricant.

◊ Vents are usually attached to the overflow. This will provide a path for air to get out of the die.

◊ A strategically placed overflow can be used to add heat in a cold area of the die.

◊ It can be used to help eject the casting from the die. Overflows typically have an ejector pin located on them. By locating the overflow in an area of the die requiring ejection, the overflow can help lift the casting out of the die.

Summary

There are many reasons a product designer would choose die casting over a competing process. Die casting produces components at high speed from a range of durable metal alloys while faithfully capturing the most intricate design details.

In fact, many product designers do choose die casting. Product lines using die cast components cover a wide range, from automotive to electrical to furniture.

After the decision is made to use die casting, the designer and engineers must ensure the design is optimum to ensure the die casting will fill completely with metal, solidify quickly without defects, and eject readily from the die. It should do all of this while also meeting the product requirements. There are six principles that should be used when developing the optimum die casting configuration.

◊ Wall thickness should be as consistent as possible.
◊ Intersections of walls, ribs and gussets should blend with transitions and generous radii.
◊ Standard draft should be specified.
◊ Sharp corners should be minimized.
◊ Undercuts should be avoided.
◊ Dimensions with critical tolerances should relate to only one die half.
Introduction
The process of injecting liquid metal under high pressure into a reusable steel die has several variations. The variations depend on the temperature of the metal pump, the consistency of the metal when it is injected, the metal velocity, gating configuration, and the condition of the die cavity at the moment of metal injection.

After completing this chapter, you will be able to:
◊ Identify the two major methods of injecting metal into the die.
◊ List the advantages of hot chamber die casting.
◊ Explain why cold chamber die casting is used.
◊ Explain how vacuum assist can reduce defects.
◊ List three high integrity die casting variations.

The information presented in this chapter is required to understand the material presented in following chapters.

The previous chapter dealt with the die casting, its advantages and applications. In this chapter, you will learn specific information about how the metal is pumped when making a shot.

The following new terms are used in this chapter.

- **Billet**: A small metal bar.
- **Static metal pressure**: The metal pressure in the die cavity at the instant that the cavity is full.
- **Thixotropy**: The property of a fluid mixture to become more fluid as the mixture is agitated.

Die Casting Processes
Conventional die casting processes inject metal into a die cavity filled with air. As the metal passes through the gate inlet, it travels at a very high velocity, in the area of 60-100 miles per hour (95-160 km/hr).

There are two major die casting processes, hot chamber and cold chamber die casting. They get their name from the temperature of the metal pump relative to the temperature of the metal.

◊ In hot chamber die casting, the metal pump, or gooseneck, is submerged in the metal and is the same temperature as the metal.
◊ In cold chamber die casting, the metal pump, cold chamber or shot sleeve, is outside the furnace, and is cold relative to the metal ladled into it.
Hot Chamber Process

The components that make-up the shot end of the hot chamber machine are shown above. These components are described below.

The A-Frame is the structural component that suspends the shot components above and in the furnace. It is mounted to the stationary platen of the machine. It gets its name from its shape.

Mounted to the A-Frame, the shot cylinder actuates in the vertical direction. Metal is injected with a downward stroke of the shot cylinder.

A coupling connects the shot cylinder to the plunger rod and tip.

This is the rod and piston tip that pumps the metal. The piston tip has two or three grooves in it for piston rings.

Similar to an internal combustion engine, two or three rings are assembled on the plunger tip. The rings:

- Prevent metal from bypassing the tip.
- Are used to maintain metal pressure after the die cavity has been filled.

The gooseneck is the combination sleeve and metal path out of the metal pump. The metal flow must change direction; it is pushed down in the sleeve to flow horizontally into the machine. Its flow path is in the shape of a goose’s neck, hence the name of this metal pump.
The nozzle is the tube connecting the gooseneck to the die cast die. It must extend from the gooseneck, through the stationary platen, to the die cast die. It is heated to keep the metal liquid in the nozzle.

The sprue bushing, located in the casting die, is what the nozzle seats against. This is cooled to assure the metal in it freezes.

Figure below illustrates a hot chamber die casting machine cycle.

The hot chamber process is predominantly used for low melting point alloys and alloys with a small aluminum constituent.

These alloys include those made from:

◊ Lead.
◊ Tin.
◊ The Zamak family of zinc alloys, ZA8 zinc alloy and a small amount of AZ91D magnesium alloy.

With the exception of magnesium, all these alloys melt at less than 900°F (480°C). The hot chamber process runs at static metal pressures that are less than the cold chamber process. This pressure is usually in the range of 1500-3500 psi (10-24 MPa).

![Figure 3-2](image)

**Figure 3-2** - Operating sequence of the hot chamber die casting process: 1. Die is closed and hot chamber is filled with molten metal; 2. Plunger pushes molten metal through gooseneck and nozzle and into the die cavity. Metal is held under pressure until it solidifies; 3. Die opens and cores if any retract. Casting stays in the ejector die half. Plunger returns pulling metal back through nozzle and gooseneck; 4. Ejector pins push casting out of the ejector die. As plunger uncovers filling hole, molten metal flows through inlet to refill gooseneck.
Cold Chamber Die Casting
The components that make-up the shot end of the cold chamber machine are shown below. These components are described as follows:

The C-Frame is the structural framework that supports the shot components. It is mounted to the stationary platen of the machine. It gets its name from its shape.

The shot cylinder is mounted to the C-Frame. Metal is injected with a horizontal stroke of the shot cylinder.

A coupling connects the shot cylinder to the plunger rod and tip.

This is the rod and piston tip that pumps the metal. Conventional cold chamber plunger tips do not have rings. The newest technology in cold chamber plunger tip design indicates that the tip may benefit from a design with rings. The tip is made from highly conductive material and is water-cooled.

The cold chamber is the shot sleeve or tube that the plunger slides in to pump the metal.

Figure 3-3 - Cold chamber shot end components.
The cold chamber process is predominantly used for high melting point alloys and alloys with a significant aluminum constituent. These alloys include those made from Aluminum, Copper, Magnesium, Iron, Titanium, and Composite materials.

If the metal pump were submersed in the metal at the melting points required by these alloys, it would not have enough strength to hold up. In the case of aluminum alloys there is another problem. Aluminum has a great affinity for iron. Liquid aluminum would dissolve the iron in the cold chamber if it were submersed in aluminum alloy.

The cold chamber process also runs at relatively high static metal pressures. This pressure is usually in the range of 3500-7000 psi (24-48 MPa).
Hot Chamber Advantages
The hot chamber process has several advantages compared to the cold chamber process:

◊ Metal temperature control is better maintained because the metal does not need to be transferred to the metal pump.
◊ Metal transfer is not required, the metal pump refills automatically.
◊ Cooling of the piston tip and sleeve is not required.
◊ There are fewer oxidation losses because the metal is disturbed and agitated less.

Process Variations
In addition to the basic hot and cold chamber processes, there are several new technology process variations.

These new technologies have been developed to provide castings that are denser than those made from conventional processing. They use high vacuum, squeeze casting, or semi-solid and thixotropic melting/casting methods.

Conventional die casting's biggest limitation is internal porosity. Internal porosity is due to trapped gases or solidification shrinkage.

The conventional die casting process injects metal at a high velocity into a die cavity filled with air. This very turbulent flow traps and mixes with the air in the cavity, causing gaseous porosity.

Through the application of high metal pressure this gas is compressed, and in many cases is not even visible. However, in other cases it may cause the casting to be defective. In castings where strength and pressure tightness is critical, the trapped gases could cause the casting to be defective.

To minimize porosity due to trapped gases, the die cavity can be evacuated using a vacuum pump. If a conventional die casting process is using vacuum to help vent the die cavity it is considered vacuum assist (26-27 inHg). High vacuum die casting refers to a strictly controlled die casting process where the air in the cavity is completely removed. Vacuum systems for high vacuum die casting are below 50 mbar of vacuum.

Squeeze casting differs from conventional die casting.

◊ Gate velocity is much lower.
◊ Gate thickness is much higher.
◊ Metal pressures at the end of cavity filling are much higher.

The gate velocity with this and the other high integrity die casting processes is very slow. It is not turbulent. In other words, the metal flows into the cavity with a solid front, in such a way that all the air in the cavity can flow out of the vents without mixing with the metal. This slow flow is referred to as laminar flow. This flow is typical of what occurs in the gravity casting processes.
Gate thickness in conventional die casting range from 0.010-0.150 inches (0.25-4.0mm). Typically, these gates freeze quickly, in many cases, before the casting is completely solidified. The squeeze casting process requires that the gate freeze after solidification in the cavity is complete. This is needed to assure that as shrinkage takes place, additional metal is forced through the gate into the cavity. Gates of the required thickness cannot be removed by trimming/shearing, but must be sawed or machined.

The metal pressures used in squeeze casting are very high, in the area of 15,000-20,000 psi (103-138 MPa). This is required to feed solidification shrinkage.

Semi-solid means that the alloy cast is part liquid and part solid. Since most die casting defects form when the casting solidifies, the idea is that the solid material in the liquid/solid mix will be free of defects.

The semi-solid process starts with a billet of material that is preheated in a specially constructed induction heater. Once the billet reaches the casting temperature it is picked up with a manipulator and placed in the cold chamber. The billet is then injected. This process also uses low gate velocities and high metal pressures to make very dense castings.

This process takes advantage of the thixotropy of various alloy mixtures. For example, the semi-solid billet is not fluid in the preheated condition; it can be handled without losing its shape. However, when it is injected and forced through the gate, literally sheared and agitated, it flows like a plastic material.

Thixomolding® is a process that takes advantage of this principle. The injection system is a combination of the screw used in plastic injection and the plunger used in conventional die casting.
Summary
There are two major die casting processes, hot chamber and cold chamber die casting.

◊ In hot chamber die casting, the metal pump, or gooseneck, is submerged in the metal and is the same temperature as the metal.
◊ In cold chamber die casting, the metal pump, cold chamber or shot sleeve, is outside the furnace, and is cold relative to the metal ladled into it.

The components used in each process are similar. The processes are used for different alloys based on the alloy’s melting point. The hot chamber process has several advantages over the cold chamber process.

Process variations are based on new technologies of high vacuum, squeeze casting, or semi-solid and thixotropic melting/casting methods. These processes try to overcome conventional die casting’s limitation of internal porosity.
Introduction
The die casting machine, DCM, is very complex. It consists of mechanical, electrical, hydraulic and safety systems that must all work together.

In this chapter, each system and its components will be identified, as will other types of specialized DCM’s. A short description of other additional equipment will be discussed.

Die Casting Machine Systems
The DCM is made up of several systems. Each system contains specific components. The DCM’s systems are; Structural; Electrical; Hydraulic; Safety.

Structural Components
The structural components are the framework of the machine, similar to the skeleton in the body. These components carry and support all the other machine components. The main purpose of the DCM base is to support the major DCM components. Its shape is generally a rectangular box and usually extends under the entire DCM. On some very large DCMs, the base may only support the back of the DCM, and a separate support used for the front.

Figure 4-1 - Line Drawing of a DCM with the base highlighted.
Many DCM manufacturers enclose the rear portion of the DCM base to form a steel tank. This tank becomes a reservoir for the hydraulic fluid/oil that powers the DCM. When the DCM runs, it generates heat. This heat goes into the oil, raising the oil temperature. For safe operation, oil temperature should not exceed 120°F (50°C). If it gets too hot, it can lose its lubricity and fire resistance.

![Figure 4-2 - A sight glass and thermometer mounted to the DCM reservoir.](image)

In addition, the oil must be kept clean to operate efficiently. The reservoir is equipped with a thermometer to check oil temperature, and a sight glass to check the oil level/cleanliness.

The “rear” of the DCM is the end of the DCM where the closing or clamping mechanism is located. This is generally where the electrical utilities, motors, and pumps are located. The “front” of the DCM is where the injection mechanism or “shot end” is located.

The DCM base must be strong enough to support the clamp and shot ends without sagging. The DCM must be properly mounted to be level, straight and square to avoid sagging or twisting.

**Platens**

The platens are the three large plates that carry the DCM loads and they rest on the DCM base. They are called the stationary platen, moving platen, and rear platen.

![Figure 4-3 - The DCM platens shaded and identified.](image)
Stationary Platen (1)
The stationary platen, located at the front of the DCM, holds the stationary die half on the die space side. The shot mechanism, either an ‘A’ frame or a ‘C’ frame, is mounted to the other side.

Moving Platen (2)
The moving platen is located between the stationary and rear platens. The moving or ejector half of the die is mounted to the moving platen on the die space side.

Rear Platen (3)
The rear platen is located at the rear of the DCM. The moving and rear platens are resting on “shoes” that slide on replaceable wear plates. The wear plates are mounted to the DCM base.

Both the moving and rear platens move every cycle.
◊ The moving platen slides back and forth to open and close the die.
◊ The rear platen slides back and forth as the tie bars stretch and relax. The rear platen is also known as the adjustable platen due to its movement to accommodate die height (thickness) adjustment.

2 Platen Die Casting Machines
A 2 platen die cast machine removes the rear platen. Instead, each tie bar will have a hydraulic cylinder. The hydraulic cylinder will connect the moving platen with a stop on the tie bar. The 2 platen die cast machine has the following advantages and disadvantages when compared to a 3 platen die cast machine:

Advantages:
◊ Even loading (all tie bars have same locking force)
◊ Constant locking force regardless of die growth
◊ Faster cycle (constant electronic tracking of platen allows quicker automation of entire die)
◊ Less wear points

Disadvantages:
◊ Machine cost (controls are more expensive)
◊ More sophisticated (higher maintenance cost)
◊ Higher hydraulic pressure (hydraulic cylinder size a limit to locking force)
Tie Bars

A typical DCM has four tie bars. The tie bars are long, round, solid beams mounted through the four corners of the platens. They are used to hold the DCM together. The moving platen actually slides along the tie bars.

Strength and size

The size and strength of the tie bars determines the size of the DCM. Every cycle the tie bars actually stretch to develop the force that is necessary to hold the die closed against the force of injection. If the DCM is improperly set-up or somehow a tie bar becomes over-stressed, it is possible to break the tie bar.

Toggle Mechanism

The toggle mechanism connects the rear and moving platens to each other. This mechanism may look different depending upon the DCM manufacturer, but it always performs the same function.
Toggle mechanism development
It takes a great deal of force to stretch the tie bars and lock the DCM. If this were to be accomplished with a hydraulic cylinder, the cylinder required would be very large and move slowly because of the large amount of oil that would be required. Indeed, some older DCMs in the 1940’s did have very large cylinders.

2 platen die cast machines go back to the original idea of using a hydraulic cylinder to open and close the die halves. The difference with modern 2 platen die cast machines is that they utilize a hydraulic cylinder on each of the tie bars. This allows the die to close faster and more evenly distribute locking forces than one massive cylinder in the center.

Die casting machine engineers developed the toggle mechanism to overcome the deficiencies of using a large cylinder. The toggles act as levers and gain a mechanical advantage during die close and locking. This allows the use of smaller closing cylinders that can operate at higher speeds. The toggle mechanism is also referred to as a linkage, because it links the rear and moving platens.

Electric Components
Electrical energy is used to power and control the DCM. The electric power is converted to hydraulic energy in order to do the actual work of the DCM.

Electric motor
An electric motor or motors provide the power for the DCM. The motor is directly coupled to the hydraulic pump. Electrical energy is converted into hydraulic energy when the electric motor spins the hydraulic pumps. The pumps force oil into the hydraulic lines under pressure.
Location

The motor is located at rear of the DCM, adjacent to the reservoir. Also, at the rear of the DCM is an electric power cabinet that encloses the motor starters and the DCM control logic. A disconnect switch is mounted on the outside of this panel along with provisions to lockout the machine when necessary.

The motor(s) operate at high voltage, typically 440/480 volts. This area must be kept clean and dry in order to avoid an electric shock hazard. The couplings between the motor and pump must be guarded because these rotate at high speed and could cause injury if contacted.

Figure 4-6 - The electric motor is located at the rear of the DCM, near the reservoir (left) The main electrical panel for the DCM. It is usually located at the rear of the DCM, near the reservoir (right).

Figure 4-7 - Typical solenoid valve.

Figure 4-8 - Typical limit switches with tailrod actuator.

Solenoids

Solenoids are used to shift the valves that control the volume and direction of hydraulic oil flow. The solenoid/valves are relatively robust but should not be abused.
Limit Switches
Limit switches are the sensors, the eyes and ears, of the electrical control system. They are located in many different places on the DCM. They are used to sense the position of doors, guards, cylinders and other moving components on the DCM.

Safe operation
Their maintenance is essential to the safe operation of the DCM. Limit switches must never be defeated or tied back. Broken connectors and exposed wiring at limit switches should be repaired immediately in order to assure safe operation of the DCM. The trip rods or actuating mechanisms at the limit switch create pinch points.

The DCM may also have other types of switches and sensors. Some of the limit switch functions may be accomplished with proximity switches. There may be pressure switches that react to a given level of hydraulic pressure.

Hydraulic System Components
The DCM is operated by a hydraulic system. This means that a fluid, fire-resistant oil is used to power the cylinders that make the DCM move. This hydraulic system operates at high pressures and high flow rates.

The hydraulic fluid is hot and can cause burns. Leaks and spills should be repaired and cleaned up quickly. These not only waste costly oil but also can cause slippery surfaces that could result in injuries if someone slips and falls.
Pumps
A DCM typically has two hydraulic pumps.
◦ One pump is capable of providing oil at high pressures but in low volumes.
◦ A second pump is capable of providing a high volume of oil at low pressures.

For example, the pumping capabilities of a 400-ton (363 metric ton) DCM may be 8 gallons per minute (30 L/min) of 2000-PSI (13.7 MPa) oil from the high-pressure pump and 40 gal/minute (151 L/min) of 40-PSI (.3 MPa) oil from the low-pressure pump.

This type of pumping capability is used to solve the various demands of the DCM. The die close cylinder requires a large amount of oil to open and close the moving platen. Once the die faces close, only a small volume of high-pressure oil is required to stretch the tie bars and lock the die. Just the act of closing requires the output of both pumps.

Filter(s)
Filter(s) are required to keep the hydraulic fluid clean. The filter(s) are located at the outlet of the pumps to assure that clean oil is sent to the various valves and cylinders.

Maintenance
The filters require routine maintenance to make sure they work properly. Most filters have a visual differential pressure gauge on them that should be checked to make sure that the oil is clean. Small dirt particles in the oil can cause valves to fail because of the small clearances in the valves.

Valves
Valves are used to control the amount and direction of oil flow. Solenoid-operated valves are used to direct the flow to the head or rod side of a cylinder or they may direct oil to shift a large valve, such as the pilot operated check valve at the base of the accumulator.
Some of the valves may be manually operated. For example, the valves controlling the speeds of injection or die closing may be fitted with large hand wheels. These valves are used to control the oil flow rate or to shut off the oil flow.

On more modern DCMs the speed control of DCM functions is controlled by a series of valves mounted on a manifold. The manifold provides a centrally-located source of hydraulic fluid for the speed control valves.

Heat Exchanger
Most DCM’s have a heat exchanger. This is a large tubular tank located adjacent to the reservoir. It operates similarly to a boiler. Hot hydraulic oil and cooling water run through the heat exchanger. The water cools the oil.

Leakage
Leakage in the heat exchanger can be troublesome. Hydraulic oil could be contaminated by water or the cooling water could be contaminated by the hydraulic fluid. If hydraulic oil temperature is excessive, the operation of the heat exchanger should be checked.

Hydraulic Cylinders
Hydraulic cylinders are used to: Open and close the DCM; Inject the metal into the die. They also may be used to: Operate the ejection system; Move slides on the die; Actuate a safety ratchet and open and close a safety door at the die parting line. These cylinders may be oil or air operated.

Die Close, Ejection & Shot Cylinders
The die close cylinder is used to open and close the die. Some DCMs have cylinders to actuate the ejection system on the die. The shot cylinder is used to inject the metal into the die.
Injection Components
The hot chamber injection components include the shot cylinder, plunger coupling, plunger, rings, gooseneck, bushing and nozzle. An “A” frame that is attached to the stationary platen supports all these components. These components inject the metal into the die. The cold chamber components include the shot cylinder, plunger rod and tip, coupling and the cold chamber.

Accumulator
The accumulator is simply a large steel tank. This tank is partially filled with hydraulic oil. Above the oil is nitrogen gas. An accumulator is used when a large volume of oil is required. This could be during die open or close, or during injection and intensification.
Figure 4-17 - Multiple accumulators located near the shot cylinder (left). The intensifier is built into the shot cylinder manifold (right).

**Intensifier**
The intensifier is a hydraulic device that increases the hydraulic fluid pressure at the end of the injection stroke. The purpose of this high pressure is to dramatically increase the metal pressure in order to squeeze additional metal into the die cavity as the metal shrinks and to further compress trapped gases.

**Safety Components**
The die casting workplace has many hazards associated with it. Everyone must be aware of the hazards and work safely. The DCM operates with high pressures, high forces, and high voltages using liquid metal at high temperatures. To operate safely in this hazardous environment, the DCM is equipped with a number of safety devices.

**Die Space Area**
The die space area, the area where the casting die is mounted, is protected by safety doors or gates. These devices prevent access to this area when the DCM closes and remains closed during a portion of the overall DCM cycle. Guards are located at the toggle mechanism to prevent access to this mechanism when the DCM is operating.
Safety

**Ratchet**

Many DCM’s are equipped with a safety ratchet. This device prevents the DCM closing. The DCM will only close if numerous safety conditions have been met and the ratchet dog is withdrawn.

**Summary**

Each DCM consists of several systems:

- **Structural**
  - The structural system and its components form the basis of the machine, providing support.

- **Electrical**
  - The electrical systems and its components provide power to the machine and control it.

- **Hydraulic**
  - The hydraulic system and its components use a fluid, fire-resistant oil to power the cylinders that make the DCM move.

- **Safety**
  - The safety components help prevent injuries and accidents while using the machine, when used appropriately and coupled with safety-conscious actions.
Introduction
Along with the DCM, the casting die is the other major component in the die casting system. The casting die has four functions:

1. Hold the molten metal in the shape of the desired casting.
2. Provide a means for the molten metal to get into the space where it is held in the desired shape.
3. Remove heat from the molten metal to solidify the metal.

In this chapter, the casting dies’ major components will be identified and defined. After completing this chapter, you will be able to:
- Identify the four types of casting dies.
- Identify the three major casting die modules.
- Identify the purpose of each major die component.

Casting Die Ownership
Customarily, the OEM owns the tooling required to make the die casting. If General Motors needed a die casting, for example, GM would pay the cost of the casting die and associated tooling needed to manufacture the die casting.

GM would then have the option of manufacturing the casting in its own die casting plant or of purchasing the casting from a custom producer of die castings. Recall that a custom die caster only manufactures die castings.

- If GM opted to purchase the casting from a custom producer, the custom producer would buy the casting die from a toolmaker and then sell the die to GM.
- If GM opted to manufacturer the casting in its own plant, GM would buy the die from a toolmaker directly.
Types of Casting Dies

Conventional casting dies come in various forms.

◊ Single cavity die: produces one casting at a time.
◊ Multiple cavity die: produces more than one casting at a time.
◊ Family die: produces a number of different parts.
◊ Unit die: explained in detail below.

A casting die can be divided into three modules based on the functions of the components within each module.

◊ Stationary mold base: Contains the stationary cavity, couples the die to the shot mechanism of the DCM and mounts to the stationary machine platen.
◊ Moving mold base: Contains the moving cavity and is mounted to the ejector box.
◊ Ejector box: Contains the ejector mechanism, couples the ejector mechanism to that of the DCM and mounts the moving die half to the moving platen of the DCM.

The unit die is not a complete die, per the description given above. The simplest unit dies consist of the stationary and moving cavities, and ejector plates and pins. With the unit die system, the OEM owns the unit die and the custom die caster owns the mold base or unit die holder.

◊ Advantages (to the OEM) of the unit die system include: Lower tooling costs; Shorter lead times; Potentially lower piece part costs.
◊ Disadvantages are: Reduced flexibility in part design; Limited size; Possible inability to move tooling from one vendor to another without additional tooling costs.
Major Die Components
Casting dies have many components.

The mold base is the steel envelope that is designed to hold all the other die components together. It is split or parted into two halves, “stationary” and “moving”. This split is known as the parting line.

During normal operation, the opening and closing of the die creates a pinch hazard at the parting line. All personnel must be aware of this pinch hazard, as it can be very dangerous.

The die parting line can also spit metal if the die is not completely closed during injection. This can be a burn hazard to anyone in the vicinity of the die. This area is normally protected with safety doors and shields.

The mold base is usually made from a pre-hardened steel such as a P-20 or AISI 4140. Although tough, it is not necessarily very hard, and care must be taken when handling the mold base to avoid damaging it. It can be nicked or dented by rough handling, which can cause set-up problems if the mold base does not fit flush on the machine platens.

Figure 5-3 - Both mold base die halves identified in this view.
The stationary half mold base has a number of components and features that are important to the die’s function.

◊ Its most important function is to act as a container for the stationary die cavities.
◊ It provides a means for attaching the stationary die half to the machine.
◊ It couples the injection system of the machine to the die.
◊ It provides a means for aligning to two die halves.

**Clamp slots**

A clamping slot is usually found around the outside perimeter of the stationary mold base. This slot is normally a standard distance from the platen mounting surface with a standard width and depth to accommodate the die/clamps that are available in the die cast shop.

In some shops, the clamp slots may only exist on the horizontal or vertical sides. In others, a clamp hole may exist instead of the slot. Slots around the perimeter are recommended as these give the greatest clamping versatility.

**Guide pins**

Guide pins, round pins located at the four corners of the die, assure the alignment of the two die halves. Some castings have critical dimensional alignment requirements of a feature in the stationary die half related to a feature in the moving die half. The guide pins in one die half and the bushings in the other die half are used to maintain this alignment.

The guide pins can be located in either die half. As the guide pins project from the parting line they can become a snag hazard when castings are removed from the die or the die is being sprayed with die release. The guide pins also operate at an elevated temperature and could also be a burn hazard.
Usually, one of the four guide pins is offset in order to prevent incorrect assembly of the die. In some special cases, these pins may be rectangular instead of round. These are called guide blocks and work in conjunction with wear plates in the opposite die half.

**Pryslots**

Pryslots are gaps at the parting line of the die, located at the corners adjacent to the guide pins, used to pry open a die when it is not on the machine.

A pry bar or wedge-shaped tool is inserted at the pryslot, and worked like a lever to open the die. This levering is done at all the corners, sequentially, in order to move the die half off the guide pins or out of the bushings. Because the prying action tends to bind at the pins and bushings, the pryslots are located near them.

Additionally, the stationary mold base has many holes in it. The holes:
- Accommodate the cold chamber or sprue bushing/nozzle.
- Provide pockets for the cavities.
- Are used for cooling lines and as mounting holes.

**Mounting/clamp plate**

Some dies have a clamp plate bolted to the stationary mold base usually to accommodate standardized or automated clamping systems. Sometimes the plate is just a spacer to adjust the shut height of the die. These plates are not recommended as they are a barrier to heat transfer to the machine and do not add to the rigidity of the die.
The functions of the moving half mold base are very similar to those of the stationary half mold base. Its most important function is to act as a container for the die cavities. It couples the ejection system to the cavities and it provides a means for aligning the two die halves.

The ejector system of the die, the ejector box, is mounted to the moving half mold base. This mold base is full of holes that create pockets for the die cavities, provide space for the cooling lines, and ejector pins. There are also a variety of mounting holes.

**Guide bushings**
Guide bushings are round holes located at the four corners of the die, designed to accept the guide pins. With the guide pins, their purpose is to align the two die halves. If the die uses guide blocks, the bushings are replaced with wear plates for two sides of the guide blocks.

The ejector box refers to the area that encloses the ejector system of the casting die. There are no specific rules as to how this area of the die is to be constructed, although it must:

◊ Provide a means for mounting the moving half mold base to the moving machine platen.
◊ Support the moving half mold base against the machine closing force and the force of injection.
◊ Couple the machine ejector system to the die ejector system.

In some cases the ejector box will totally enclose the ejector system, in other cases only top and bottom or sides will be enclosed.

**Parallels/rails**
Parallels are steel plates that are located between the moving half mold base and the machine moving platen. They are called parallels because the “contact” surfaces are parallel.

Parallels may have clamp slots cut into them to mount the moving die half to the moving machine platen. In other cases the parallels act as a spacer between the moving half mold base and a clamping plate.

Parallels are usually made from steel plate such as AISI 4140. They must be strong enough to prevent them from being “squished” or compressed. Remember, if the machine exerts a locking force of 1000 tons (907 metric tons) to hold the die shut, the parallels must support this 1000 tons (907 metric tons).

**Clamp plate**
Some dies have a plate bolted to the parallels for the purpose of clamping the moving half mold base to the machine. This plate, depending on its thickness, may have a clamp slot cut into it.

**Support pillars**
Inside the ejector box there may be columns extending from the moving half mold base, through the ejector plates, to the machine platen or clamp plate. These round or rectangular columns are located in line with the die cavities and are designed to support the mold base against the force of injection.
Inside the ejector box is the ejector system. This provides one of the four critical die functions, to ‘provide for removal of the solidified metal.’

The ejector system includes plates and pins as a minimum, and may additionally include guide pins and bushings and other sophisticated components to provide specialized ejection features.

![Ejector Box Components](image)

**Figure 5-8 - The ejector box components are accented in this sketch.**

### Ejector pins

Ejector pins extend from the ejector plate to the casting. They may actually be located on the casting and/or at other locations on the “shot”.

The ejector pins leave marks on the casting. These ejector pin marks may vary in height, with respect to the adjacent casting surface, and may be subject to special quality requirements. For example, the height of these ejector pin marks may be subject to a dimensional requirement such as “flush to 0.020 depressed” with respect to the casting surface.

◊ If the ejector pin is too long, it will leave an indentation that may make it difficult to remove the casting from the die.

◊ If the ejector pin is too short it will leave a raised boss on the casting that may be objectionable.

There also may be a maximum flash requirement at the ejector pin mark. Since the ejector pin is subject to many stresses during operation, failures occur. An operator’s job is to minimize breakage. The pin must be properly lubricated and not bent or bumped during operation.

Ejector pins, when extended, pose both burn and snag hazards. When reaching in to remove the shot, the operator must be aware of the ejector pin locations in order to avoid contacting or snagging them.
Return pins
Return pins are used to return the ejector system to its “home” position before the next shot. The return pins extend from the ejector plate to the parting line.

During the ejection stroke the return pins do not push on anything, but extend above the parting line. When the machine closes, the return pins contact the stationary half parting line and push the ejector plate back to the “home” position.

On some machines the ejector plate is coupled directly to the DCM and the ejector cylinder pulls the plate back to the home position before die closing and the return pins become redundant. Even with this redundancy, return pins are recommended to provide returning of the ejector plates in case of failure.

Return pins, when extended, pose both burn and snag hazards. When reaching in to remove the shot the operator must be aware of the return pin locations in order to avoid contacting or snagging them.

Ejector plate
The heads of all the ejector pins rest on the ejector plate. As the ejector plate moves forward, it pushes on the pins and ejects the casting. A machine motion moves the ejector plate forward. This can be by:

◊ Knockout rods that operate between the ejector plate and a fixed plate or surface on the DCM as the DCM opens.
◊ A hydraulically-operated bumper plate or an ejector cylinder.

Ejector retainer plate
The ejector retainer plate retains the heads of all the ejector pins and is bolted to the ejector plate. This plate is necessary to hold the pins in place when the ejector system is returned to the “home” position.

As the ejector plate and retainer plate assembly move back and forth between stops during normal operation, pinch hazards are created in these areas. If the ejector box is not totally enclosed, access to these pinch areas is possible.

Guided ejection
Sometimes it is necessary to make sure the ejector system operates smoothly and uniformly. To achieve this, guide pins and bushings are added to the ejector system.

There are several components to the die cavities. The cavity blocks, core pins and slide actually form the casting. Other components, such as the carrier, wedge lock and cam pin, are required to move the slide. Cooling lines and heaters are used to achieve the correct temperature balance in the cavities.

Cavity blocks
The term cavity blocks includes all the specialized tool steel that is used to form the actual casting. This includes core pins, interchangeable inserts within the cavity blocks and various slide cavity components.
These pieces are usually made from AISI H-13 steel. This is a specialized hot work tool steel made to exacting specifications for chemical analysis, density, homogeneity, and grain size, to name a few. This steel is comparatively expensive to purchase. After the initial toolwork is done, it is subjected to rigorous heat treatment that must conform to a series of exacting specifications.

The cavity blocks, although hard, can easily be nicked or damaged. Consequently, they must be handled extremely carefully. If they are nicked or damaged, those defects will show up on the casting. The tools used to remove a stuck casting or piece should be softer than the cavity block. Brass is usually recommended. Please never use screw drivers or wedge ground ejector pins.

The cavities can also be damaged in a less obvious way, by how the die is run. The cavities will last longest if they are always preheated to a minimum of 350°F (177°C) and if they normally run within a temperature range of 400-600°F (204-316°C).

Core pins
Core pins are similar to ejector pins, however their size tolerances are slightly different. Core pins are usually used to cast round holes in the part, but their shape is not restricted to being round, only the shape of the core pin body must be round. Core pins can be very fragile and fail if not taken care of. They must be sprayed with die release in order to prevent the build-up of solder.

Slides
Sometimes features are cast that cannot be created with the normal opening and closing of the die. This can be done with a component called a “slide”.

The motion of a slide is in a direction different than normal opening and closing. A cavity feature can be mounted on a slide, and then this slide is withdrawn from the casting before the casting is ejected. If the slide is mounted in the stationary die half, then the slide must be withdrawn before the DCM opens the die. The slides may be actuated either with a hydraulic cylinder or mechanically with a cam pin.
The in and out motions of slides create numerous pinch and strike hazards. The operator must be aware of the location of these hazards in order to avoid being caught by them. Some slide mechanisms rely on springs to hold the slides in position when the die is open. If the spring or part of the carrier fails, these pieces could become a projectile and a strike hazard.

**Carrier**
The cavity portion of the slide is normally mounted to a carrier. The carrier moves the cavity back and forth with a cam pin or a hydraulic cylinder.

**Wedgelock**
The carrier is held in place with a wedgelock. The wedgelock is a piece of steel with an angled surface that is forced against the carrier to hold it in place against the force of injected metal.

**Cam pin**
The cam pin is mounted into the stationary mold base at an angle. It fits through a hole in the slide carrier and causes it to slide in and out with the closing and opening motion of the machine. Cam pins, when extended, pose both burn and snag hazards. When reaching in to remove the shot, the operator must be aware of the cam pin locations in order to avoid contacting or snagging them.

**Cooling lines**
Most cavity blocks have cooling lines in them. These are necessary to perform one of the basic die functions, to ‘remove heat from the molten metal to solidify the metal.’ The cooling lines may be designed to carry either water or oil as a cooling medium.

Some lines are equipped with special high pressure and high temperature hoses and fittings, which must be maintained in good repair. Failure could result in a burn hazard. In addition to the burn hazard, the fittings should be maintained to prevent leakage, and leaks should be quickly repaired because of the danger of a slip fall hazard.

![Figure 5-11 - These cooling lines are drilled through the cavities and mold base.](image)
Heaters
Some dies may use electric cartridge heaters to control temperature instead of cooling lines, or in addition to cooling lines. These heaters have wiring associated with them to power them. The wiring can pose a shock hazard if not properly maintained.

Die Cavity
There are a number of cavity features that share the same terminology as the die cast shot. These are the sprue, runner, gate, overflows and vents.

Biscuit block
Generally, cold chamber dies have a separate piece of AISI H-13 steel in the moving die half opposite the cold chamber. This block is the beginning of the metal distribution system (runner) to the casting cavities.

Sprue bushing
In the hot chamber system, the sprue bushing has the important job of being the liquid metal to solid metal interface. At the junction of the nozzle and sprue bushing, the metal in the nozzle must always remain a liquid and the metal in the sprue bushing must solidify.
Sprue post
The sprue post has a job similar to that of the biscuit block. The post is the beginning of the metal distribution system. Proper cooling in the post is very important to consistent operation of the die.

Stop buttons
Stop buttons limit the forward and return travel of the ejector plates. The DCM’s ejection system pushes the die ejector plates to forward stop buttons during the ejection stroke. Then the ejection system or return pins pulls/pushes the plate back to the rear stops to ready the die for the next cycle.

Quick eject cam and pins
This system is used to push the casting off of the primary ejector pins and out of the die. This is a “secondary” ejection system. The “primary” ejection system pushes the casting out of the cavity. Another use for a secondary ejection system is to separate the casting from the runner system.

The figure below shows a view of a two cavity casting die with many of the components identified.
Summary
The casting die is the other major component in the die casting system and has four functions. Castings can be manufactured by the OEM or purchased from a custom producer.

There are four casting die forms: single cavity, multiple cavity, family and unit. A typical die contains three modules: stationary mold base, moving mold base and the ejector box. Unit dies are not complete dies and have certain advantages and disadvantages for the OEM.

There are many components to casting dies.

- Mold base
- Stationary half mold base
- Moving half mold base
- Ejector box
- Ejector system
- Die cavities
Introduction

Four major alloy groups account for most of the functional and decorative die castings produced in North America: aluminum, magnesium, zinc and ZA.

These alloys have a range of properties and characteristics that make them ideally suited for many applications. In layman’s terms, the properties of die cast alloys are slightly less but overlapping with sheet steels and are greater than but somewhat overlapping with high strength plastic resins. This chapter will discuss the properties and characteristics of the four major alloy groups.

After completing this chapter, you will be able to:
- Correctly identify the most common alloy from each major group.
- Identify the alloy with the highest strength.
- Identify the major alloying ingredients from an alloy specification.
- List nine important criteria used to select an alloy for a particular job.

In the previous chapters you learned about the die casting, DCM and tools. In this chapter you will learn about the alloys used in the die casting process.

The following new terms are used in this chapter.

- **Tensile strength**: The maximum stress achieved when pulling a test specimen in the direction of its length, usually expressed as pounds per square inch.
- **Yield strength**: The level of strength at which elastic strain becomes plastic strain, the stress at which permanent deformation takes place.
- **Elongation**: Amount of permanent extension in the vicinity of the fracture in the tension test.
- **Modulus of elasticity (MOE)**: Slope of the elastic portion of the stress-strain curve in mechanical testing.
Mechanical Properties

Often the casting designer will consult a table of the mechanical properties of the die casting alloys before making the final alloy selection. Table 6-1 is such a reference.

Mechanical properties of typical interest are:

- Tensile strength (ultimate).
- Yield strength.
- Elongation (ductility).
- Modulus of elasticity (MOE).

Each of these is a property that predicts how the alloy will react to a stressed condition. A “strong” alloy has high values of tensile and yield strengths, and low values of elongation. A “weak” alloy has low strengths and higher values of elongation.

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<td>6.5</td>
<td>-</td>
</tr>
<tr>
<td>Impact strength (Charpy), ft/lb</td>
<td>3.0</td>
<td>40</td>
<td>2.0</td>
<td>43.0</td>
</tr>
</tbody>
</table>

Table 6-1 – Comparative properties table

The element Aluminum has a specific gravity of 2.71, placing it among the lightweight structural metals.

As a base for a die casting alloy, it has three primary alloying ingredients: silicon, copper and magnesium. All the other ingredients can be called impurities. In some cases these impurities must be controlled at specific levels, in other cases the level of impurity may be an economic compromise.
Table 6-2 lists the elemental specifications for typical aluminum die casting alloys. Table 6-3 is a comparison of die casting and product characteristics for various common die casting alloys.

<table>
<thead>
<tr>
<th>Nominal Composition</th>
<th>360</th>
<th>380</th>
<th>383</th>
<th>390</th>
<th>413</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg – 0.5</td>
<td>Cu – 3.5</td>
<td>Cu – 2.5</td>
<td>Cu – 4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si – 9.0</td>
<td>Si – 8.5</td>
<td>Si – 10.5</td>
<td>Si – 17.0</td>
<td>Si – 12.0</td>
<td></td>
</tr>
</tbody>
</table>

Molten aluminum alloy has a high affinity for iron. Conventional aluminum alloys for high pressure die casting contain around 1% iron to minimize the soldering between aluminum and iron in the die steel. This iron content can limit the mechanical properties of the casting.

Aluminum alloys designed for structural die castings reduce the iron content to improve casting properties. Adding small amounts of strontium to the alloy will reduce soldering in alloys with less than 4% iron content.

**Product applications**

380 aluminum alloy is most commonly used because it offers the best combination of casting and product properties. It is used for the widest variety of products; lawn mower housings, electronics chassis, engine components, home appliances, hand and power tools.

383 and 384 are alternatives to 380 that are specified when very intricate components require improved die filling characteristics and improved resistance to hot cracking. The silicon in each of these alloys is increased over that specified for 380 alloy.

360 alloy offers improved corrosion resistance and superior strength at elevated temperatures compared to 380 alloy, both copper and zinc are reduced in this alloy compared to 380 alloy.

443 alloy offers the greatest ductility of the aluminum die casting alloys.

413 alloy offers excellent pressure tightness. It is also highly fluid and useful for intricate detail. Its silicon constituent is near the eutectic composition.

390 alloy offers the greatest wear resistance. It has a very high silicon constituent and was developed for the Chevrolet Vega engine block.

518 alloy has very good corrosion resistance and ductility. It is used in marine and aircraft hardware and also in escalators.
Magnesium
The element magnesium has a specific gravity of 1.74, making it the lightest commonly used structural metal. As a base for a die casting alloy, it has four primary alloying ingredients: aluminum, zinc, manganese and silicon. All the other ingredients are impurities and are controlled to maximum limits.

Table 6-4 lists the elemental specifications for typical magnesium die casting alloys. The alloy designations are easy to interpret. AZ91D alloy is 9% Aluminum, 1% Zinc, with the letter D indicating that this is the fourth revision of this specification.

AZ91 alloys can be cast in either hot or cold chamber DCMs. AM60A and AS41A alloys must be cast using the cold chamber process.
Product applications
AZ91D is the workhorse alloy in the magnesium group. It is found in drive train automotive components as well as handheld and laptop computers.

AM60A is an alloy with aluminum and manganese. It has good elongation (ductility) and toughness (ability to absorb energy before failing). It is used in automotive wheels and steering wheels and archery equipment.

AS41A is an alloy with aluminum and silicon. It has creep strength at elevated temperatures. These properties made it a choice for air-cooled automotive crankcases in the VW Beetle.

Zinc
The element zinc has a specific gravity of 6.60, putting it among the heavier commonly used structural metals. It is less dense than iron (s.g. 7.7) and copper (s.g. 9.0).

As a base for a die casting alloy, it has three primary alloying ingredients: aluminum, magnesium and copper. All the other ingredients are impurities and are controlled to maximum limits. Table 6-5 lists the elemental specifications for typical zinc die casting alloys. Zinc 3 and 5 were introduced in the 1930’s and 7 was introduced about 20 years later.

Many times these alloys are referred to as Zamak. Zamak is an acronym with Z for zinc, a for aluminum, m for magnesium, and k for copper. In the United Kingdom, they are called Mazak.

Zinc is the highest purity of the die casting alloys. This is because small amounts of cadmium, lead and tin can lead to intergranular corrosion and actual deterioration of the component. The maximum allowable amount of these elements is in the 20-40 parts per million range. The need to have these impurities at these very low levels gave rise to the common expression “get the lead out”.

<table>
<thead>
<tr>
<th>Alloy Type</th>
<th>Zamak Alloys</th>
<th>ZA Alloys</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Composition</td>
<td>#2</td>
<td>#3</td>
</tr>
<tr>
<td>Al-4.0</td>
<td>Al-4.0</td>
<td>Al-4.0</td>
</tr>
<tr>
<td>Mg-0.035</td>
<td>Mg-0.035</td>
<td>Mg-0.055</td>
</tr>
<tr>
<td>Cu-3.0</td>
<td>Cu-1.0</td>
<td>Cu-0.013</td>
</tr>
</tbody>
</table>

Table 6-5 - Alloy chemistry of common zinc die casting alloys.

Product applications
#3 zinc is the workhorse alloy of this group; it is specified most frequently for functional and hardware castings.

#5 zinc has higher tensile strength, hardness, and creep resistance. It also has somewhat lower ductility. This is due to the increased copper content. A common application is automotive locks.

#7 zinc is a high purity form of #3 alloy. It has slightly lower hardness and higher ductility. It has higher fluidity than either #3 or #5, and could be a better choice for thinner walls and finer detail.
The ZA alloys were developed in the late 1950’s. Recent research and development has refined the chemical composition and adapted this alloy group to die casting.

Since the late 1970s they have been aggressively marketed because of superior properties as compared to the Zamak alloys in terms of:

◊ Wear resistance.
◊ Creep resistance.
◊ Higher strength.
◊ Lighter weight.

There are three alloys in this group, ZA-8, ZA-12, and ZA-27. The number indicates the nominal amount of aluminum in the zinc alloys. Again, the ZA alloys are alloys of zinc, aluminum and copper.

ZA-8 with 8.4% aluminum and 1% copper has the lowest melting point and highest density of the three alloys. It has the highest strength of any hot chamber alloy and highest creep strength of any zinc alloy.

ZA-12 with 11% aluminum and 1% copper typically has properties between ZA-8 and ZA-27. It must be cold chamber die cast because of its elevated melting point and aluminum content. It can be chrome plated.

ZA-27 with 27% aluminum and 2.2% copper has the highest melting point and highest strength and lowest density of the three alloys. It must be cold chamber die cast because of its elevated melting point and aluminum content. It is not normally chrome plated.

**Alloy Selection**
The following nine categories assist in the selection of the optimum die casting alloy. This selection process is required because the four families of alloys offer a wide latitude of properties and characteristics, and choices of trade-offs must be made.

**Alloy Cost**
Alloy cost is an important factor in the overall product cost, particularly among die casting alloys.

Alloy prices tend to fluctuate with market conditions. Prices are quoted on a weight basis, usually per pound. However, alloy is used on a volume basis. A casting has a fixed volume, usually stated in cubic inches. Therefore, for comparative purposes, the cost of alloy should be converted to a volume basis.

Aluminum alloys usually have the lowest cost per cubic inch. Sometimes magnesium and zinc can be competitive because they may be cast with thinner walls and their volume reduced.

**Process Cost**
Process cost is another important component of overall product cost.

Alloys run with the hot chamber process usually run in smaller DCMs and at higher production rates than equivalent casting with the cold chamber process.
Although initial tooling cost is usually equivalent, maintenance and replacement costs can vary significantly. Zinc tooling has the longest life and aluminum tooling the shortest. This is easily understood if one looks at the differences in temperatures and heat loads that the various alloys put into the tooling.

Magnesium and zinc alloys can be cast to greater precision than aluminum, reducing or eliminating secondary operations.

Zinc and ZA-8 tend to be the material of choice for very small die castings. This advantage is attributable to the specialized high-speed four slide zinc machines.

**Structural Properties**

Structural properties vary from alloy to alloy as shown in table 6-1. Aluminum alloys have the highest modulus of elasticity (MOE) of the four alloy groups. Their relatively high strength and low density makes them a choice for medium to large die castings with structural requirements.

Magnesium, with lower strength and rigidity, has been competitive with aluminum in some applications through strategic placement of reinforcing ribs. ZA alloys offer the highest tensile and yield strengths.

**Weight**

Minimum weight can be another important choice characteristic. Magnesium alloys are the dominant choice if weight must be minimized.

**Dent Resistance**

Impact strength and dent resistance are the highest among the zinc (Zamak) alloys. Impact strength of the zinc alloys diminish sharply as temperature is reduced below 32°F (0°C). Impact resistance of aluminum and magnesium alloys varies within each alloy group.

<table>
<thead>
<tr>
<th>Alloy:</th>
<th>Yield Stress (ksi)</th>
<th>M.O.E (ksi x 10^6)</th>
<th>$\frac{\sigma_s^2}{2E}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>380 Aluminum</td>
<td>23</td>
<td>10.3</td>
<td>26</td>
</tr>
<tr>
<td>AZ91 Magnesium</td>
<td>23</td>
<td>6.5</td>
<td>41</td>
</tr>
<tr>
<td>390 Aluminum</td>
<td>52</td>
<td>11.8</td>
<td>52</td>
</tr>
<tr>
<td>ZA-8</td>
<td>41</td>
<td>12.4</td>
<td>68</td>
</tr>
<tr>
<td>Zinc 3*</td>
<td>31</td>
<td>6.3</td>
<td>79</td>
</tr>
<tr>
<td>ZA-27</td>
<td>57</td>
<td>11.3</td>
<td>143</td>
</tr>
<tr>
<td><strong>Sheet Steel:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 ksi</td>
<td>40</td>
<td>29.5</td>
<td>27</td>
</tr>
<tr>
<td>60 ksi</td>
<td>60</td>
<td>29.5</td>
<td>61</td>
</tr>
<tr>
<td>90 ksi</td>
<td>90</td>
<td>29.5</td>
<td>137</td>
</tr>
<tr>
<td><strong>Powdered Iron:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FC-020S-45</td>
<td>50</td>
<td>19.5</td>
<td>64</td>
</tr>
<tr>
<td>FC-0508-60</td>
<td>70</td>
<td>17.5</td>
<td>140</td>
</tr>
</tbody>
</table>

*Table 6-6 - Properties Related to Dent Resistance.*
Dent resistance is the ratio of yield strength to MOE. For identical features with equal wall thickness, ZA-27 offers the highest dent resistance, followed by ZA-12 and ZA-8. The yield strength to MOE ratios are nearly equal for aluminum and magnesium alloys.

**Surface Finish**
Surface finish is best achieved by the zinc and magnesium alloys. This is because of their compatibility with the die steel. Die steel surface quality is essential to casting surface quality.

**Corrosion Resistance**
Corrosion resistance varies from alloy to alloy with an alloy group. Aluminum alloys vary according to the chemical composition, particularly copper. Magnesium alloys vary with metal purity. The more resistant alloys offer moderate corrosion resistance. Corrosion resistance can be improved with low-cost surface treatments.

**Wear Resistance**
Bearing properties and wear resistance for all the die cast alloys is good for hydrodynamic bearing applications, i.e., where oil is fed under pressure and full film lubrication is achieved. Where only partial lubrication is available, the ZA alloys and 390 aluminum offer good resistance to abrasion and wear.

**Machinability**
Machinability of all die casting alloys is excellent. Magnesium alloys offer the best machinability in terms of tool life, energy consumption and low cutting forces.

The following chart shows which alloys are the best choice in each of the nine rated categories.

<table>
<thead>
<tr>
<th>Selection Category</th>
<th>Al</th>
<th>Mg</th>
<th>ZA</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Alloy Cost by Volume</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Process Cost</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Tooling life</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Most Precise</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>3. Structural Properties</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Small</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium to Large</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOE - High strength/low density</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOE - High tensile and yield strength</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Weight - light</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>5. Impact Strength (I)/ Dent Resistance (DR)</td>
<td>X (DR)</td>
<td></td>
<td>X (I)</td>
<td></td>
</tr>
<tr>
<td>6. Surface Finish</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Corrosion Resistance</td>
<td></td>
<td></td>
<td></td>
<td>Varies within each type according to chemical composition and metal purity. Can be improved with surface treatments.</td>
</tr>
<tr>
<td>8. Bearing Properties/ Wear Resistance</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Hydrodynamics</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Partial Lubrication</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>9. Machinability</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Tool life, energy consumption, low cutting forces</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 6-7 - Alloy Selection Chart.*
Freezing Behavior of Alloys

Think about how water freezes. When water freezes, it freezes at one temperature, 32°F. Pure metals freeze the same way. If water is at room temperature, in order to get it to freeze, you must lower its temperature to 32°F, and then continue to cool it, until it freezes. The temperature versus time graph below shows the freezing behavior of several pure metals that are present in die casting alloys, zinc, aluminum, copper, and silicon. In all cases the various metals freeze at a particular temperature for that metal.

When most alloys freeze, the time versus temperature chart is slightly different than that for elements (pure metals) and compounds. Only one combination of an alloy mixture behaves like a pure metal, the eutectic alloy mixture. The solidification curves for various aluminum alloys are shown in the time versus temperature chart. For most alloys the time versus temperature chart shows a freezing range. The amount of this freezing range varies depending on the alloy.

Alloy Quality

Alloy chemical composition is controlled by an ASTM, American Society for Testing and Materials, specification. Any casting manufactured to one of the ASTM specifications must be within the specifications. In other words, there is no room for error.

Each die casting plant, as part of its quality control procedure, has a method for maintaining alloy quality. This begins with the purchasing of material, and continues through the manufacturing process and shipment.

A component of alloy quality is cleanliness. This is not as easily checked as chemical composition. Each time the alloy is melted, some of the material is oxidized, combines with oxygen in the atmosphere. The oxides are impurities in the alloy that could affect the casting’s properties if not removed. Again, each plant has processes in place to minimize the amount of oxidation and has cleaning processes to remove the oxides from the alloy.
Summary

Die casting designers consider a range of issues when creating a die casting. Each alloy has different mechanical properties: tensile strength, yield strength, elongation, and MOE. The alloy chosen must be appropriate to the die casting’s application.

Alloy selection is based on the characteristics and properties of the alloys in nine categories. These include:

- Cost by volume
- Process cost
- Structural properties
- Weight - light
- Impact strength/dent resistance
- Surface finish
- Corrosion resistance
- Bearing properties/wear resistance
- Machinability
Introduction
Machinery and equipment, in addition to the DCM, may be required to produce a die casting. This equipment and its function in support of the die casting manufacturing process is discussed in this chapter.

Depending on how the plant you work in is set up, you may have some or all of the equipment that is discussed. Following the equipment discussion, the fundamental steps of a typical DCM machine cycle are discussed.

After completing this chapter, you will be able to:
◊ Correctly identify all machinery and equipment in a workcell.
◊ Identify the purpose of each piece of equipment and alternative methods that can do the job of a particular piece of equipment.
◊ List the fundamental steps of the die casting cycle.

Modern Die Casting Work Cell
A modern die casting work cell usually contains the following equipment:
◊ DCM
◊ Holding furnace
◊ Ladle
◊ Die sprayer
◊ A plunger tip lubricator, for cold chamber die casting only

Figure 7-1 - 1200 ton DCM workcell auto ladle, reciprocator and extractor.
Some Work Cells may also Contain:
- An extractor/robot
- A quench
- Conveyors
- Die heaters
- A trim press/die

A mixture of these machines is commonly used, depending on the:
- Complexity of the castings produced.
- Sophistication of the manufacturing operation.

For example, a die caster specializing in short production runs may only require a DCM, a furnace, a hand ladle, a spray wand and a brush to lubricate the plunger tip. On the other hand, a producer of large castings, such as transmission cases or engine blocks may use all the equipment that is listed.

Holding Furnace
The holding furnace provides liquid metal to process, maintains the metal at a preselected temperature, keeps the alloy free of contamination from air or other sources, and receives metal.

This can either be cold chamber or hot chamber processes.

Cold Chamber
Location
This furnace is located adjacent to the DCM to minimize metal transfer distances. Some die casters will also use this furnace to melt the metal.

Description
A typical cold chamber die casting holding furnace will have three distinct chambers:
- Charge well
- Bath
- Dip well

These chambers are connected below the metal level with an arched passage.

Charge Well
Metal enters the furnace at the charge well. This metal is usually delivered to the holding furnace, in liquid form, from the remelt furnace. In some cases metal may be charged as ingot or gates and runners.

Covering
When not in use, the charge and dip wells should be covered to prevent oxidation, energy loss and extraneous material from getting into the furnace.
**Furnace bath**
The furnace bath is the main section of the furnace and contains the bulk of the metal.

**Combustion**
It’s heated with electricity or fossil fuels. If it is gas or oil fired, steps must be taken to ensure complete combustion. Either a “rich” mixture or “oxidizing” mixture can lead to problems with metal quality.

**Preventative maintenance**
Combustion should be checked periodically as a preventative maintenance issue. Preventative maintenance of electrically-heated furnaces is directed toward keeping seals and heating elements in good condition.

**Cleaning**
The metal bath must be cleaned periodically. This could be once a shift or once a week, based on maintaining metal quality and furnace efficiency. Since many of these furnaces use radiant heating as the energy transfer method, they work best when the furnace is full and the metal is clean.

**Dip Well**
The dip well is the third metal chamber. The metal is ladled or dipped and then transported to the cold chamber from this well.

**Metal quality**
Metal quality can be improved if a filter is placed between the main bath and the dip well. As metal flows from the bath to the dip well, it passes through the filter, which removes contaminants and oxides.

**Temperature control**
The holding furnace temperature is controlled with a thermocouple. The thermocouple in cold chamber holding furnaces is normally located in the dip well.
Hot Chamber

Location
The hot chamber holding furnace is located adjacent to the stationary platen. It is under the “A” frame that supports the shot cylinder and shot end components, and suspends the gooseneck in the metal bath.

A hot chamber machine’s holding furnace is much simpler than a cold chamber holding furnace. Hot chamber metals, with the exception of magnesium, are less reactive with oxygen than cold chamber metals. These furnaces typically are open crucibles, or pots. They can be fossil fuel-fired or electrically-heated. They generally are not covered, however benefit from being covered, both in terms of energy and oxidation losses.

The temperature control thermocouple is located near the gooseneck. Metal temperature and quality are two very important die casting process variables.

Ladling (Cold Chamber Only)
Ladling is the process of moving the liquid metal into the cold chamber and can be done manually or with an auto ladle. The objective in ladling is to achieve a clean, consistent metal volume with a minimum of energy loss. Consistency assures that the process variables dependent on the shot volume occur with reasonable accuracy.
Importance of ladling consistency
A biscuit size difference as small as ¼ inches (6mm) can be very significant with respect to forming defects. For this reason it is important to ladle a consistent amount of metal.

Typical ladling consistency issues

**Excessive metal ladled**
If too much metal is ladled, the sleeve will fill quickly and metal will also fill the runner and gate before the plunger reaches the (slow to) fast limit switch. In this case the metal could start filling the cavity at very low velocity causing defects and possibly freezing at the gate.

**Insufficient metal ladled**
If too little metal is ladled, the plunger will arrive at the fast shot limit switch before the chamber is filled with metal. This could result in lots of turbulence and mixing air with metal in the sleeve and porosity defects in the casting.

Ladling clean metal
Pouring clean metal is part of the ladling objective. Since the dip well of the holding furnace is usually not covered during operation, the metal is exposed to air.

◊ The metal in contact with the air oxidizes.
◊ Aluminum forms aluminum oxide and zinc forms zinc oxide.
◊ It is undesirable to have these oxides in the casting.
◊ Usually these oxides float on top of the metal bath and are referred to as “dross”.

Oxides are usually not a problem in hot chamber die casting because the gooseneck filling holes are below the metal surface in the holding furnace.
Manual ladling
When ladling manually, the operator must make sure the dross is not allowed into the ladle. The recommended procedure is to use the ladle to push the dross back from the surface and dip out clean metal.

Auto ladling
The auto ladle also pushes the dross out of the way to dip out clean metal. Periodically the dross must be skimmed from the top of the dip well, or eventually it will get into the ladle. Auto ladles are very good at pouring a consistent amount of metal.

Manual ladling advantages and disadvantages
Manual ladling of metal has several distinct advantages over auto ladling:
◊ Manual ladling is quicker and results in less heat loss
◊ Metal can be poured to minimize turbulence
◊ The shot can be initiated quicker
◊ It has a low implementation cost

Disadvantages:
◊ Operator fatigue when large shot sizes are required
◊ Inconsistency in the volume of metal poured

Ladling time and filling defects
Metal loses temperature when not being heated and then begins to solidify when enough temperature is lost. This means that the amount of time that ladling takes is an important process variable.
◊ When heat is given up by the metal and the metal begins to freeze and become slushy, it is difficult for the plunger to push this metal through the gate and fill the cavity.
◊ This results in poor filling defects.

Auto ladles usually operate at a slower pace than a person does, particularly in the case of small shots, those less than 5 pounds. Setting up the auto ladle sequence and monitoring the consistency of operation is important. The auto ladle should dip out the metal, transfer it to the cold chamber, and pour it without any delays.

Die Spray
The die spray applies a protective coating of release material on the die face with a minimum of die spray. It also provides cooling in areas that cannot be cooled internally.
Die spray can be applied through different appliances:
- A manually held spray wand
- Individual spray nozzles mounted in fixed positions on the machine or die
- A series of spray nozzles mounted on a moving arm that reciprocates in and out between the open die faces, called a reciprocator

The reciprocating arm could be mounted to the machine, floor or boom of an extractor.

Each of these application methods has advantages and disadvantages.
Excess die spray
After spraying, excess die spray is blown out of the die cavity and flash or build-up is blown from the die face.
- Excess spray that is left in the die cavity can turn to steam and end up as gas porosity in the casting.
- Excess build-up and flash at the parting line could cause the vents to plug.
- Excess flash can also hold the parting line open and cause dimensional problems and spitting.

Importance of consistency
As with ladling, consistency is a key to successful die spray application. If spraying is done with the manual spray wand, several important process variables are under the operator’s control.

Spray pattern
The spray pattern is important to assure that the release material is getting to the die cavity surfaces that need release material. These surfaces are features that are directly in the metal flow path, in front of the gate, where the metal has high velocity. This also includes surfaces perpendicular to the parting line with minimal draft and surfaces that are not adequately cooled.

Spray time
The time taken to apply the die spray is very important because it directly affects the total cycle time.

Cycle time is another of die casting’s major process variables. It controls the temperature balance between the die and casting. The relationship between die spray time and cycle time is “direct.” This means that as die spray time increases, cycle time increases, and as die spray time decreases, cycle time decreases. The overall objective of cycle time is to run as short a cycle as possible, keep the die as hot as possible, and use as little die spray as possible.

Consistency in spray time leads to consistency in cycle time because spray time is one of the elements of the cycle that is under operator control if the die spray is manually applied.

Spray applied
The amount of die spray applied is another important process variable. The operator should apply the minimum amount. Die spray works best when applied at temperatures of 450-550°F (230-290°C). If the die is hot, castings will have a better surface finish and the die surface will last longer.

Die spray should not be running from the face of the die and flooding the floor. If cooling is needed, this should be done with clear water. Excessive flooding with die spray will only wash the die spray off. Excess die spray must be blown out of the die prior to the die closing.
Fixed position sprayers and hot chamber die casting

Fixed position sprayers that are mounted to the die or machine platens have been very successful in hot chamber die casting. Hot chamber metals have very little aluminum in them, reducing the amount of die spray that is necessary. In some cases, the die can be sprayed intermittently, every 3, 4, or 5 cycles.

Fixed head sprayers are limited to the areas that they can reach. A major advantage of the fixed head sprayer is that it:

◊ Can apply spray quickly.
◊ Is always in position to spray when the die is open.

If high shot rates are to be achieved (short cycle times) of 300-400+ shots per hour, a fixed sprayer is the only alternative, for a maximum of a 1 to 2 second spray in an overall cycle of 10 seconds.

Reciprocator use

◊ Can spray faster than a person.
◊ Is very flexible.
◊ Can be programmed to position itself at various locations between the die faces
◊ Can spray and blow-off for various time periods.
◊ Can use multiple liquids, such as die spray and water.
◊ Can be programmed to pulse (less lube usage).

Excess die spray and flash

After spraying, excess die spray is blown out of the die cavity and flash or build-up is blown from the die face.

◊ Excess spray that is left in the die cavity can turn to steam and end up as gas porosity in the casting.
◊ Excess build-up and flash at the parting line could cause the vents to plug.
◊ Excess flash can also hold the parting line open and cause dimensional problems and spitting.

Plunger Lubrication

The plunger lubricator lubricates the tip without material that will contaminate the metal. This is most easily accomplished with lubricants that are applied behind the tip, with the excess being wiped out of the sleeve on the return stroke.

Lubricant must be applied to the plunger tip when using a cold chamber. Many methods are available for applying tip lube, from a simple brush and pail to sophisticated methods for applying liquids, dry lubricants, and powders.
Some older methods of application include:
◊ Brushing heavy petroleum lubes into grooves in the plunger tip.
◊ Dripping the lube on the tip every cycle.
◊ Mounting a fixed nozzle above the cold chamber pour hole and spraying a water-based lube into the cold chamber.
◊ Drilling the plunger rod with spray holes behind the tip, connecting this line to a spray nozzle, and spraying lube into the sleeve during the return stroke.

Some newer methods include:
◊ Dropping dry lubricants into the pour hole.
◊ Spraying powdered lubricant inside the sleeve.

Lack of proper plunger tip lube is the most common cause for erratic shot end performance.

Casting Removal
The casting must be removed from the die after the shot is made. Casting removal can be accomplished manually, with a mechanical aid, or with a mechanized extractor or robot.

Manual removal
With manual removal, the operator must be aware of the safety hazards associated with reaching into the die area. These hazards are minimized through adequate operator training and proper maintenance of the DCM safety devices. Use of proper tools is recommended to prevent operator risks.

Mechanized removal
Many die casting operations use mechanized methods for casting removal. These methods include: Sophisticated robots; Simple extractors; and custom-built machines.

Mechanical methods of casting removal are slower than manual removal. They are an advantage in achieving cycle consistency and when heavy castings must be removed. Safety hazards are reduced using mechanical removal, but proper safety precautions are required to prevent the robot or extractor from creating a new hazard.

Drop through removal
The fastest method of casting removal is “drop through” operation. The casting is ejected from the die and allowed to fall out via gravity. The casting may drop on a conveyor or into a quench tank. A scale, limit switch door, or heat sensing device may be used to detect the casting and recycle the machine.

Quenching
Quenching is the forced cooling of the die casting. Quenching is used to achieve rapid cooling and dimensional stability.

As the casting cools to room temperature, it is changing size, contracting. If the die cast workcell includes trimming and other secondary operations, it is best to do them with castings that are dimensionally stable. If the castings are force cooled to room temperature they will be dimensionally stable.
Cold water quenching
The most common form of quenching is to dip the hot casting into cold water. This has the advantage of working very quickly.

There are several disadvantages:
◊ After the quench all water must be removed from the casting or it will corrode. Inhibitors can be added to the quench water to minimize this problem.
◊ A water quench can be very messy: water gets on the floor, and becomes a slip-fall hazard. Additionally, spilled water must be cleaned-up and disposed of properly.
◊ A very rapid quench can cause internal stress in the casting. Large, thin walled castings may distort dimensionally.

Forced air quenching
Forced air quenching is blowing cool air over the hot castings. This takes longer than water quenching, but the increased time is offset by the advantages of eliminating the water mess and disposal problems.

Die Casting Work Cell
The die casting workcell may include:
◊ Conveyors, chutes, and slides for moving the castings to the next operation, or to move scrap back to the remelt furnaces.
◊ Baskets or pallets for stacking castings in batches for subsequent operations.
◊ Other containers for accumulating scrap.

Die Heaters
Die heaters are important to the die casting process. They:
◊ Preheat the casting die prior to startup.
◊ Maintain the die temperature during production.

The objective of preheating the die is to get it to a minimum temperature of 350°F (175°C) before subjecting it to the thermal shock of the first shot.

Some die heaters are used exclusively to preheat the die prior to production. These can be stick torches, hand torches, or electric radiant heaters.
Importance of die preheating
Die preheating is extremely important. Putting hot metal into a cold die is a considerable shock. At low temperatures, impact strength is low, and at high temperatures, impact strength is high. This means the die temperature should be high in order to have high impact strength and resist thermal shock.

Concerns when heating
When preheating the die with gas torches, care must be taken to:

◊ Avoid overheating die components with the open flame. If a hand torch is used, not acetylene, it must be moved continuously to avoid excessive heating.
◊ Avoid overheating parts of the cavity and insufficiently heating other areas of the cavity.

For example, if a stick torch is resting on the leader pins in a partially open die, the flame will impinge on projections from the cavities and no heat will reach the recesses. If a projection, such as a core pin, were to get so hot that it began to change color to a deep cherry red, the core has been overheated, and its heat treatment destroyed.

Heating options
Electric radiant heaters heat the cavities more uniformly, from top to bottom, but have some difficulty in heating deep pockets. Electric heaters operate at voltages 2 to 4 times greater than household voltages and can be a shock hazard. Safety requires that wires are in good condition, not frayed or bare, and that all connectors are secure and all boxes covered.

The best option to achieve die preheating is to use some form of internal heating, either electric cartridge heaters or circulating hot oil. These heat from the inside to the outside and also have some sort of temperature control associated with them.
Working with large dies
Large dies are difficult to preheat. There are several alternatives.

◊ The die can be preheated off line and then set-up hot. This is not any different than removing a hot die. This prevents the machine from becoming a big heat sink.
◊ Cover the die with an insulating blanket.
◊ Make sure that no fan is blowing cold air over the die.

Maintaining die temperature
A second job of die heaters is to maintain the die temperature once the die is in production. This is best accomplished with internal cartridge heaters or hot oil circulating in cooling lines.

The die casting process is a heat exchange process, heat is put into the metal to melt it in a furnace, the metal is injected into the die, and the metal solidifies, cools and gives up heat to the die. The more uniform this process is in terms of temperatures and times, the more predictable it is in terms of dimensions and defects. Uniform cavity temperatures yield uniform shrinkage and predictable dimensions.

Trim Press
Die cast workcells sometimes include a trim press or other equipment. The DCM machine operator or team may be responsible for running this equipment.

Description and use
The DCM operator or team may be also responsible for:

◊ Utilities provided to the workcell.
◊ Housekeeping.
◊ The set-up of the workstation.

Utilities
Utilities such as high-pressure air and electricity are delivered in hoses and wires. Safety requires that the hoses and wires are damage-free. These utilities are best tied down, secured and out of walkways.

General housekeeping
In general, housekeeping must be maintained.

◊ The floor space must be kept free of safety hazards such as wires, hoses, piping, grease and dirt.
◊ Work platforms must be elevated to the proper height in order ease the strain on the DCM operator.
◊ The workstation should be arranged to minimize the amount of work that must be done.
◊ Convenience trays and tables are arranged to simplify and ease the workload.
Fundamental Machine Cycle Elements
The machine cycle consists of eight sequential cycle elements (seven in hot chamber die casting).
- The cycle begins as soon as the casting made in the previous cycle has been removed.
- The first cycle step is to prepare the die cavities with die release application, followed by machine closing, ladling (cold chamber only), injection, dwell, machine opening, ejection, and casting removal.
- Each step must be done consistently to assure a quality casting and good die life.
- Additionally, for manually operated machines, the operator must interface with the machine during the cycle in a safe and predictable manner.

Casting Inspection
After the casting has been removed, but before it is set aside, it should be quickly inspected for completeness and obvious visual defects. This is done before the next cycle step, die spray.

This inspection is kept short in order to maintain the rhythm of the casting cycle. After the die spraying is complete and the next cycle initiated, during the dwell time, a more thorough examination of the part can be made.

Die Spray
Applying die spray is the next step in the casting cycle. This is an opportunity to inspect the die. The die should be inspected for:
- Flash on the parting line, in the vents, and in slide pockets.
- Soldering and lube build-up.

After die spraying is complete, the die should be blown off with high-pressure air to assure that no liquid is left in the die cavities. In addition, the die parting line should be cleaned to remove any flash.

The objective of the die spray is to put a protective barrier on the die, to shield it from the aluminum in the die casting alloy. This barrier is only one millionth of an inch thick, and is replaced every cycle.

Die spray also can be used to remove heat from areas that are not accessible to internal cooling. If additional cooling is required, use atomized water first and follow up with die spray before the die cavity is too cold. Die spray should not run from the face of the die.

Starting the machine cycle
There are several acceptable methods for starting the casting machine cycle.
- Double palm buttons are the most common cycle start mechanism
- Safety door closure
- Combination of door closures and palm buttons

Whatever method is selected as being safe should not be bypassed.
Satisfying safety conditions
Once the safety door is closed, the machine cannot close and lock the die until all safety conditions and cycle sequence conditions have been satisfied. These conditions include, but are not limited to, the following.

<table>
<thead>
<tr>
<th>If the:</th>
<th>Then:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machines and dies employ hydraulic coupled ejection</td>
<td>The ejector plate must be “home” in the returned position. This must be done if ejector pins are located under slides and would interfere with a slide in the “home” position. An ejector plate limit switch is required to prove if the ejector plate is “returned”.</td>
</tr>
<tr>
<td>Die has ejector half-hydraulic cores</td>
<td>The cores must be in “cores out” position. This must be proved with a limit switch.</td>
</tr>
<tr>
<td>Die has stationary half-hydraulic cores</td>
<td>The cores must be in the “cores out” position. This must be proved with a limit switch.</td>
</tr>
</tbody>
</table>

Additional safety requirements at the machine include that the:
- Safety pawl is engaged
- Guards are in place over and around the toggle/linkage mechanism
- Safety doors are in place, preventing access to the die space
- Ejection cylinder is returned, home
- The die close cylinder is in the open position
- The injection cylinder is in the home position.

After all the conditions are satisfied, the safety pawl is withdrawn and the machine can begin closing.

Injection / making the shot
Before injection can occur, a number of process and safety conditions must be satisfied:
- The die must be locked
- The plunger must be at the home position
- All safety doors and barriers must be in place
- The plunger tip must have been lubed and be cooling properly

The injection sequence begins when metal is poured into the cold chamber. The metal is dipped from the holding furnace and transferred to the cold chamber as quickly as possible, to minimize heat loss, and with as little disturbance as possible.

Dwell Time
After the shot has been completed, and prior to die and machine opening, the metal must be allowed to freeze and gain strength. During dwell, the casting is cooling in the die. The casting would also like to contract, but it cannot because it is trapped in the die.
Because the casting cannot contract as it cools, the stress that would otherwise be released with the heat energy stays in the casting and becomes what is known as an internal stress. If the casting is kept in the die too long, and this internal stress is greater than the strength of casting, the casting will crack.

Experience and experimentation determine dwell time. Initially, the dwell time is set long enough to ensure that the biscuit will freeze and not become an explosion hazard. Slowly, dwell time is reduced, to a point where a lack of hot strength is indicated.

Indicators of lack of hot strength include:
- The ejector pin bulging, or in the worst case, the part sticking in the ejector half with the pins poking through.
- Pieces of the casting sticking in the stationary die half.

**Die Opening**

Just as with die locking, die opening requires high pressure to relieve the tie bars.

With cold chamber die casting, the machine needs to open slowly initially. The plunger must push out the biscuit and keep it in contact with the ejector die until it is fully out of the shot sleeve; otherwise the biscuit might stick in the sleeve and bend the runner and casting. Once the biscuit is clear of the stationary die, the safety door may be opened.

With normal die opening, the casting is in the ejector half cavity of the die. With some castings there is no way of predicting in which die half the casting will remain. In those cases, the tooling engineer must ensure the casting remains in the ejector half. If the casting has mechanical slides, a slight delay can be built into slide withdrawal by adding clearance to the cam pin hole in the slide carrier.

**Ejection**

The next step in the cycle is ejection. Ejection can be accomplished by a number of different methods.

**“Bump” ejection**

This is the simplest method. An actuator supplied by the machine simply bumps the ejector plate of the die, pushing the casting out of the die. After the part is ejected, the pins remain extended until the die closes and the ejector plate is pushed home when the ejector return pins “kiss” the parting line.
Fixed plate ejection
This method uses a fixed plate behind the moving platen. Long pins or knock-out rods are placed in holes in the moving platen, and extend from the die ejector plate to within several inches of the fixed plate. When the machine opens, the knock-out rods are squeezed between the fixed plate and the ejector plate of the die, pushing the ejector plate forward. Again, the ejector pins remain extended until the die closes and the ejector plate is pushed home when the ejector return pins “kiss” the parting line.
Other, more sophisticated methods, can be used to actuate ejection. A common method is to couple a hydraulically-operated bump plate to the die ejector plate with threaded knock-out rods.

Casting Removal
After the casting is ejected, it must be removed from the die. Removal of the casting must be done with care, otherwise the die and casting can be damaged.

◊ A pliers or tongs should be used to grip the biscuit or runner to remove the casting from the die.
◊ The tool should not be used to grip the casting directly, as this could leave damaging marks on the casting.

The use of a tool for removal is recommended for several reasons. The tool:

◊ Provides leverage to get a firm grip on the casting without having to squeeze the tool very tightly.
◊ Gets hot from repeated handling of hot castings, but by using insulated grips or hose over the grips, the operator is insulated from the burn hazard.
Preventing damage
The casting should be pulled straight off of the ejector pins. If the casting is wiggled and twisted, the ejector pins will flex and bend, and put pressure on the ejector pin hole causing it to wear and become bell-mouthed. This bell-mouthed condition causes the ejector pin hole to flash, which aggravates the casting removal.

Fragile or thin walled parts may be damaged, nicked or bent if they are too difficult to remove.

Safety
Recently ejected castings are hot and are a burn hazard. Typical ejection temperatures for die castings are 750 - 550°F (400 - 290°C). Castings cool at different rates. Thin walls cool readily, while a biscuit or sprue may take half an hour or longer to cool.

Castings usually have sharp and jagged flash on them that cuts quite easily. The castings must be gripped firmly when handling them to avoid slippage and the probability of being cut.

Summary
The fundamental steps of the die casting cycle include:
- Die spray/die inspection
- Die closing
- Ladling (cold chamber)
- Injection
- Dwell/casting inspection
- Die opening
- Ejection
- Casting removal/inspection

Figure 7-12 - Using tongs to remove a casting.
Introduction

Die castings make high quality components. The quality of a die cast component, as judged by the end user, is determined by its appearance and ability to do the job it was designed for. However, quality of a die casting is more than skin deep. The quality of a die casting is also determined by its dimensional and internal integrity.

A quality casting is free of defects. So, in order to determine the quality of a casting, you must be able to identify the defects. This chapter focuses on die casting quality from the viewpoint of the types of defects that occur.

There are three common types of defects. Surface defects are discussed first, followed by internal defects and finally dimensional defects. Some of the causes for the defects will be mentioned, however this chapter is not intended to deal with causes and corrective actions; these are beyond the scope of this course.

After completing this chapter, you will be able to:

◊ Correctly identify the common surface defects.
◊ Correctly identify the common internal defects.
◊ Correctly identify the common types of dimensional defects.

Surface Defects

There are many types of surface defects. A partial list appears below. The list may vary by shift, by plant, by state or by country. Within a given plant, however, a simplified list that everyone understands should be used.

<table>
<thead>
<tr>
<th>Flow Defects</th>
<th>Other Defects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold flow</td>
<td>Blisters</td>
</tr>
<tr>
<td>Cold shut</td>
<td>Cracks</td>
</tr>
<tr>
<td>Flow marks</td>
<td></td>
</tr>
<tr>
<td>Cold</td>
<td></td>
</tr>
<tr>
<td>Flow lines</td>
<td>Soldering</td>
</tr>
<tr>
<td>Severe chill</td>
<td></td>
</tr>
<tr>
<td>Non-fill</td>
<td></td>
</tr>
<tr>
<td>Poor-fill</td>
<td></td>
</tr>
<tr>
<td>Laps</td>
<td></td>
</tr>
<tr>
<td>Knit lines</td>
<td></td>
</tr>
<tr>
<td>Mis-run</td>
<td></td>
</tr>
</tbody>
</table>

Die Casting Quality

NORTH AMERICAN DIE CASTING ASSOCIATION
Flow defects result from how metal flows to and within the die. Adjusting process variables can sometimes impact their occurrence.

Flow defects that can be impacted by adjusting process variables occur when:
- The alloy begins to freeze before the casting is completely filled out.
- Several alloy flows converge but do not weld completely together.

In both these cases, the alloy does not have enough heat energy to remain completely liquid during the fill time. These defects are usually surface blemishes that range widely in severity, from a deep crease to a barely discernible line. Or they may be so severe as a hole in a thin wall or a completely missing feature.

There are eight factors affecting flow defects. Each is discussed in detail.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill time</td>
<td>Flow distance</td>
</tr>
<tr>
<td>Wall thickness</td>
<td>Gate velocity</td>
</tr>
<tr>
<td>Die Temperature</td>
<td>Alloy type</td>
</tr>
<tr>
<td>Alloy temperature</td>
<td>Venting</td>
</tr>
</tbody>
</table>

**Fill time**

Fill time is the maximum allowable time to fill the die cavity that results in an acceptable casting. It is assumed that if the fill time is exceeded, the casting will have some unacceptable defect. Engineers calculate fill time when establishing the die casting process specification. Once a fill time is established, the engineers can calculate the various combinations of plunger sizes and plunger velocities that will satisfy the fill time requirement.

The fill time calculation is based on several factors. If any factor changes, the fill time also changes.
Factors include:

◊ **Die temperature**
  When the fill time is calculated the first time, estimates or assumptions of die and alloy temperature are made based on past experience. The estimate of die temperature may be made based on a history of measurements of similar castings in the plant.

◊ **Alloy temperature**
  The estimate of alloy temperature may be made based on a history of measurements of similar castings in the plant. When different alloys are used at a plant, usually each alloy has a preferred holding temperature.

◊ **Casting geometry**
  Casting geometry is a very important factor when determining fill time. Some castings are chunky, while others may be skinny. The engineer looks at the casting geometry to estimate how well the casting will give heat up to the die.
  - If a casting has high volume and little surface area, it is similar to a casting with thick walls. This would be interpreted as a casting with a lot of heat (volume) and little ability to give up the heat (low surface area).
  - If a casting has little volume and lots of surface area, this is interpreted as a casting with little heat (volume) and lots of ability to give up this heat (large surface area).

◊ **Alloy being cast**
  Alloy is the final factor considered when calculating fill times. Alloys behave differently when being cast. Alloys vary in fluidity, soldering ability, freezing time, etc.

**Process Parameters have a greater effect**

For purposes of calculating fill times, the engineer determines a numerical value for the casting geometry. Methods include: Calculating an average wall thickness; Determining the thinnest wall thickness; Using a nominal wall thickness.

Whatever system is used, it should be used consistently and then modified based on experience.

**Wall thickness**

Wall thickness is part of the casting’s geometry.

◊ Heavy wall sections equate to a lot of heat and high cooling requirements.
◊ Thin walls equate to very little heat and minimal cooling requirements.

If internal die cooling is not sufficient to uniformly cool the die, external cooling via water or die release spray may be used to try to balance the heat load on the die.
Die temperature
Die temperature, in the most inclusive sense, is the time-averaged temperature of the die during sustained production. For aluminum dies, a die temperature of 500°F (260°C) is preferred. The cavity surface temperature is not constant; it changes all the time, depending on the proximity of cooling lines to the cavity surface.

The concept of die temperature is somewhat nebulous. It cannot be measured any time at any place in the die. Ideally, die temperature will be as high as possible, still permit making the casting and vary as little as possible over the entire cycle. It is not unusual to see time-averaged temperature variation of over 100°F (55°C) in a die cavity.

Alloy temperature
The temperature of the alloy as it begins to fill the die cavity is where alloy temperature is measured. This is hard to measure in real time as the casting is being made.

This temperature is estimated for the purpose of fill time calculations. Reasonable estimates are that the alloy looses 50-90°F (28-50°C) as it is transferred from the holding furnace to the cold chamber and injected. Avoiding any delays in the alloy transfer can minimize these temperature losses. If the alloy is ladled automatically, there should not be any delays in the ladle cycle; the ladle should not have to wait for the machine to complete any functions.

Flow distance
Flow distance is the distance that the metal must flow once it passes through the gate. It is important because the alloy should flow to its terminal location without freezing. If the flow distance is too long and if the alloy speed is too slow, it will be difficult for the metal to fill the cavity without beginning to freeze. As the alloy begins to freeze, it becomes more viscous, and does not flow as easily.

Gate velocity
Gate velocity is the speed that the alloy travels as it passes through the gate. This is a critical variable for several reasons.
◊ If this velocity isn’t controlled, it can be detrimental to the tooling causing washout and erosion.
◊ If the gate velocity is too low, the alloy may not atomize and not have enough energy to reach the ends of the casting or to properly weld together.

Alloy type
The type of alloy can make a quite a bit of difference in the surface finish. In zinc, Zamak 7 was designed to have the best fluidity and surface finish of the common alloys. The Zamak alloys have up to 4.2% aluminum in them and the fluidity is quite a bit higher at the high end of the aluminum range; this makes a difference in thin wall castings.

In aluminum, the silicon content is important because it aids fluidity. It should be maintained at the high end of the content specification. The alloys closer to the eutectic will be more fluid and will tend to have better surface finish (384 for example).

Also, the eutectic alloys will have a smaller freezing range and will be more sensitive to variations in the holding temperature and other process variations, and so are regarded as harder to cast.
Venting

Venting and vacuum can be significant for surface defects in some cases. The trapped air will cause blisters and gas porosity, and it will also cause backpressure in the cavity. This backpressure can change the flow enough to cause surface defects.

This is most noticeable in blind features (such as bosses, fins, etc.), where the backpressure from trapped gas may be enough to prevent a complete fill in these areas. Review the metal flow pattern to find out if this could be a problem. Regions close to the last fill points will be the most affected.

To remove gases from blind features, it may be necessary to add vacuum. Vacuum is beneficial in all situations where backpressure is suspected of altering the flow path, and should be used wherever it is feasible. The other benefits of vacuum, such as reducing out-gassing, blisters, and gas porosity, make it desirable to use in any case.

Blisters

Blisters are bubble-like bumps on the casting. Gases trapped in the casting near the casting surface cause them. These gases are under very high pressure. After all, the process uses high metal pressure or intensification at the end of the shot in order to compress the trapped gases. When the casting is ejected and the casting surface over the blister is not strong enough to withstand the gas pressure of the blister, the surface yields and the blister forms.

Figure 8.2 - Blister.
Cracks

Cracks in castings come from a variety of causes. The two major causes for cracks are:

◊ **Heat**

  **Insufficient:** If the casting die or alloy is cold as the casting freezes, there will be excessive internal stresses in the casting. This, in turn, prevents sufficient hot strength in the alloy and the casting will crack in the die, and be cracked when it is ejected. This often occurs when a die is started; many first startup shots are cracked due to the cold conditions.

  **Excessive:** If the die is too hot, usually in a local area, a crack forms due to shrinkage. As the alloy solidifies it takes up less space; its volume is reduced. For aluminum alloys this volume reduction is 4 to 6 percent.

This volume reduction occurs at the last location to solidify; if no additional alloy can be forced into the die to fill this space, a void is created. Most DCM’s are equipped with intensifiers that multiply the metal pressure at the end of cavity filling, to force more alloy into the die as the alloy shrinks.

A typical hot spot could be an inside corner in a casting or outside corner of the die steel. If this local area runs hot compared to the areas surrounding it, it will cool and solidify after the surrounding areas are frozen. As it freezes it shrinks, and may cause a crack at the surface because the surrounding areas are already frozen and no additional alloy can be forced to the shrinkage site.

◊ **Externally applied stresses**

  Externally applied stresses can also cause cracks. A casting should be ejected smoothly with the ejection force distributed as uniformly to the casting as possible.

◊ **If the ejection system does not move smoothly, but jerks and shimmies, it could cause the casting to crack.**

◊ **Another cause for cracking could be damage in the cavity. As the die opens and is stripped out of the stationary half and past the location of the damage, a crack could form.**

Figure 8-3 - Cracked casting.  
Figure 8-4 - Soldering on casting.
Soldering

Soldering is the fusion of aluminum in the die casting alloy with iron from the steel surface of the die cavity. Typically, the die cavity has an oxidized coating on it. This coating protects the cavity surface from the aluminum.

If the alloy impinges on a portion of the die or on a core pin to the extent that a hot spot develops, the aluminum will break down the oxidized interface between the die surface and the casting.

Once this happens, the aluminum dissolves and alloys with the iron in the steel; the aluminum molecules actually penetrate and bond with the iron. Generally this is the same type of bonding that you get when you solder wires together using lead-tin solder.

When soldering occurs in the die casting die, the casting sticks to the cavity. The only way to get the casting out is to tear it away from the stuck surface, giving the casting a rough appearance. The alloy has been torn away. If the soldering is not removed, it will leave a blemish on the casting. The only effective way to remove the soldered spot is to remove all the aluminum and steel that has been penetrated.

Soldering is frequently seen on cores or walls that are in the path of the incoming alloy. This situation is aggravated by higher than usual die temperatures, high gate velocities and high metal pressures.

Soldering is also enhanced if the iron content in the casting alloy is low. For aluminum alloys, the minimum iron content should be 0.8% iron. This iron content can be reduced by adding 0.05-0.07% strontium. If the alloy has sludged, it is possible that the iron content is below the recommended minimum.

Insufficient draft angles also lead to soldering. When the draft angle is small, the casting at the die opening and ejection will abrade areas of the cavity. This rubbing action removes any protective oxide film and actually “primes” the die surface for soldering.

The main purpose of die release is to provide a protective barrier on the cavity surface. If the die release is ineffective, or casting conditions are such that the die release cannot get to the cavity surface or wet the surface, conditions for soldering will be present.

Internal Defects

Internal defects are detrimental to the die casting for several reasons.

The mechanical properties of a casting are such things as tensile strength, elongation, hardness, impact strength and others.

These properties are measured on samples made from the die cast alloys and are published to help designers pick a material that is appropriate for their design. These properties are measured on solid and dense samples.

If a sample was made from porous materials, the values of the properties would not be as high. In order to meet the design requirements, the casting must be made as dense and solid as possible with good clean alloy.
Pressure tightness could be a particularly important property for some applications. If a fuel pump casting is to be leak tight, the casting must be solid without internal porosity. Other castings are required to be leak tight for gases, and some others need to hold lubricants. Many casting applications require the casting to be leak tight. To produce castings that are pressure tight, the process has to be controlled while making solid, low porosity castings.

Internal defects also affect the machineability of the casting. This includes both porosity and inclusion defects.

There are two types of internal defects, inclusions and porosity.

**Al₂O₃, Aluminum oxide**

The vast majority of inclusions is non-metallic aluminum oxide, Al₂O₃. Aluminum is a powerful reducing agent and consequently oxidizes easily. This is one of the reasons for build-up inside furnaces.

The oxides of aluminum are polymorphic. When aluminum oxide first forms it is the soft gamma type with a specific gravity of approximately 2.8. This is very similar to the alloy from which it is formed. As this material is heated, it is transformed into a much denser and harder variety called alpha Al₂O₃. This is commonly called corundum and is rated next to diamond on the hardness scale. The build-up on the sidewalls of furnaces is essentially pure corundum.

Oxides find their way into the bath during the normal melting operation. Any melted alloy that is exposed to air will oxidize. If it is then agitated or disturbed, it can get under the furnace door into the main bath. Normal fluxing and cleaning operations separate the oxide from the alloy. The oxide floats to the top of the metal surface and is then skimmed out of the furnace.

Aluminum oxide may also get into the alloy bath during the wall cleaning process. This build-up of corundum is broken up and dislodged during the cleaning of the side wall or wall contact with the furnace tools during routine fluxing.

It becomes mixed with flux, alloy, air, and flue gases. The resulting particles may vary widely in size and density. Some sink to the bottom, but most is skimmed off as dross. An appreciable fraction, however, may have a density similar to the metal in the bath and will remain suspended in the melt ultimately finding its way into the dip well, and into the castings.

The color of Al₂O₃ as it appears in castings is a dull gray to black. The gradations in color from dull gray to dull black are undoubtedly related to the variations in the intense heat, which transformed gamma to alpha Al₂O₃ and the time frame in which it was formed. The size and shape of the individual corundum particles may vary widely.
Oxide films and dross inclusions
Inclusions of oxide films and dross are a major cause for leakers and excessive tool wear. This is generally gamma aluminum oxide, the soft variety. The source of these thin films can be:

◊ The cold chamber.
◊ The runner.
◊ Metal splashes in the die

These splashes and jets, ahead of the main alloy stream, are usually a result of poor gate and runner design or of improper speed control of the plunger.

The real problem of the oxide films is that they prevent divergent alloy streams knitting together properly as the cavity fills. This results in the formation of discontinuities such as laminations, orange peels, or cold shuts. If these films envelope air or vaporized die lube, blisters or excessive internal porosity results.

Silicon carbide refractories, SiC
Silicon carbide refractories can find their way into castings if furnace-cleaning practices are not maintained. SiC is as damaging as corundum because of its hardness. It is encountered infrequently compared to corundum and may be distinguished by its very black, glass-like coloring. The source can be chips from carbide crucibles or from grinding wheels used to remove soldering from the die surfaces.

Figure 8-5 - Aluminum oxide inclusion.  
Figure 8-6 - Oxide film.
Flux
Flux inclusions are not usually recognized during a cursory visual inspection. A simple test to determine whether or not castings contain flux inclusions is to simply submerge the casting in city water overnight. If flux inclusions are present, they will grow crystals on the casting surface since flux is composed of salt. The corrosive products that develop appear as light mottling on all surfaces of the casting.

Sludge
Sludge is another inclusion considered a hard spot. Sludge is composed of complex inter-metallic compounds of Al-Si-Fe-Mn-Cr. Sludge is quite hard, and in a casting will damage cutter tooling. Under high magnification sludge is easily recognized by the extremely fine primary crystals and their pentagonal shape.

Porosity
Porosity is a void in the casting. This is a problem typical to all die casters. Porosity has two root causes:
- Trapped gas.
- Shrinkage.

Trapped gas porosity has a distinctive appearance; it is round, smooth and looks like bubbles. Trapped gas for gas porosity can come from many sources. To solve a gas porosity problem, look at all sources of gas generation.
Trapped air
Trapped air is always present to some extent in conventional die casting because of the turbulent method used to fill the die cavity. The alloy atomizes as it flows through the gate. Air can also be trapped in several other ways.

Air in the cold chamber
In addition to the air trapped in the die cavity at the moment of die filling, the most common source of trapped air is in the cold chamber. Obviously, the amount of air in the cold chamber can be minimized by filling the cold chamber with alloy. This may not be practical, as there are competing requirements for minimum fill times. If the process has any adjustment in it, reaching a greater percentage of fill in the cold chamber is recommended.

The cold chamber should be 50-70% filled if trapped air porosity is a problem.

Turbulence
Another source of trapped air is when the alloy is subjected to turbulence in the presence of air. Minimize the amount of turbulence when picking up and transporting alloy to the cold chamber through ladling practices. The slow portion of the shot cycle must be controlled.

◊ First, the timing of the plunger start should be optimized. As the alloy is poured into the cold chamber, it runs down the sleeve to the parting line and is reflected at the die parting line. This wave comes back to the pour hole, and the pouring is complete, the plunger should start as soon as the wave reflects at the plunger tip. In this way the motion of the tip and wave are synchronized. The initial acceleration of the plunger is adjusted to get past the pour hole without spitting alloy out.
◊ Once the plunger tip is past the pour hole, it should be accelerated to keep the crest of the wave moving down the sleeve without folding over and trapping air. The critical slow shot speed must be used at this time.
◊ Once the sleeve is filled with alloy, and the air is being pushed out through the runner system, cavity and vents, a smooth acceleration to the fast shot speed should follow.

Improper venting
Improper venting is another cause for trapped air. The vents must be open to allow the air trapped above the alloy in the cold chamber to escape. If the vent is working properly, a puff of air coming out of the vent, as the plunger moves forward, can be seen.

Trapped gas from excessive lubricants
Lubrication is a common cause for trapped gases. If excessive die release is put on the cavities, it can result in gas from two sources.
◊ First, some of the die lube will burn up when the alloy hits it. This will result in the release of combustion products.
◊ A second problem is that most releases are diluted with water.
If excess lube is left in the die, the water in the lube will turn to steam and produce a great volume of gas. After the lube has been applied to the cavities, any excess that has collected in low spots or is trapped in the die should be blown out with air.

Another source of gas due to excessive lubrication is plunger tip lube. This gas usually forms when the alloy runs over lube that has puddled in the cold chamber. This can cause problems because it is immediately trapped in the alloy and has little chance to escape in front of the alloy wave front. As with die release, use a minimum of plunger lube.

Other sources
If the die cavity has cracks in it, the crack might allow fluid from the cooling line to leak into the die cavity. Water or oil in the cavity, when hit by the alloy, will form gas. There are several solutions to this type of problem. One is to abandon the cooling line by turning the coolant off. If cooling is critical and must be used, the alternatives are to fix the leaking crack or to use a local cooling system that pulls the coolant through the die as opposed to pushing it through.

Hydraulic cylinders can leak, and if they are above the die cavities, hydraulic fluid can run into the cavities. The seals at the rod or hose connections can be the sources of leakage at the cylinder. Care must be taken when pre-heating the die to make sure the seals at the cylinder are not burned up.

Shrink porosity, or shrinkage, is porosity that occurs if the alloy solidifies without pressure on it.

- For example, pure aluminum shrinks 6.6% by volume.
  - If you start with 100 cubic inches (1638.7 cc) of liquid aluminum, and it freezes, similar to alloy freezing in an ingot mold, the frozen aluminum will only occupy 93.4 cubic inches \((1530.5 cc)\) \((100 in^3 - 6.6 in^3 = 93.4 in^3)\) \((1638.7 cc - 108.2 cc = 1530.5 cc)\).

- Aluminum die casting alloys shrink from 3.8 to 6.5%, zinc alloys around 3-4%, and copper alloys around 4-5%.

High pressure die casting
High pressure die casting uses intensifiers or other methods to dramatically increase the alloy pressure once the cavity has been filled with alloy. It is not uncommon for this pressure to be as high as 10,000-15,000 psi \((705-1060 \text{ kg./cm}^2)\).

For intensification to work, the alloy pressure must be transmitted from the biscuit through the runner to the gate. If the gate, runner, or biscuit freeze, the alloy pressure cannot be applied to the cavity.

- Cooling that causes the gate to freeze prematurely needs to be reduced.

- Cooling at the biscuit is usually most effective. The plunger tip is made of a material that conducts heat readily, and the coolant flow in the tip is usually turbulent and unrestricted.

- For this reason the biscuit must not be too thin.

- A rule of thumb is to make sure that the biscuit is at least 30-60% thicker than the runner leading from the biscuit. This helps ensure that the biscuit freezes after the runner.
Shrink defects
Shrink defects occur at the last place in the casting to freeze, and are easy to recognize.
- Shrink porosity is characterized by a rough and jagged appearance, in contrast to the smooth appearance of gas porosity.
- This rough appearance is caused by the dendritic structure of the primary alloy component that freezes first.

Shrink porosity tends to be continuous by nature. This means the porosity tends to string together into long groups of interconnected voids. These voids can form a leakage path if they break through the surface.

As mentioned previously, shrink porosity occurs at locations that freeze last. For example, if a heavy section is surrounded by thin walls, the thin wall freezes quickly and then the heavy section freezes without any chance of high pressure alloy reaching it. A void will then form in the heavy section as shrinkage occurs, or a sink may occur at the surface.

Dimensional Defects
Section 4 of the NADCA Product Standards, provides tables of expected dimensional precision under standard or precision operating conditions in a most economic manner. The dimensional variations covered in the Product Standards are linear variation, across parting line variation, shift and mismatch, and warpage.

These tables are a guideline for casting designers. As the tables specify, they apply in economic circumstances and are not the final word with respect the epitome of dimensional accuracy. Most dimensional defects are related to Die temperature, the condition of the die and the force of injection. Die temperature is the most important variable related to dimensional precision.

Thermal expansion/contraction
A metal rod gets longer when heated. This is thermal expansion. Thermal expansion for the rod is related to the type of material the rod is made from, the length of the rod and the temperature change experienced by the rod. In other words:

\[
\Delta L = C \times L \times \Delta T
\]

- \(\Delta L\) = change in length—amount of expansion/contraction
- \(C\) = coefficient of thermal expansion
- \(L\) = length
- \(\Delta T\) = change in temperature

As objects cool they get smaller, called contraction. This behavior acts in accordance with the above formula. The difference is that instead of having a positive temperature change and adding length, there is a negative temperature change, getting colder, and the object gets shorter or smaller.
When a casting is ejected from the die and cools to room temperature, it gets smaller. Generally, all the dimensions on the casting also get smaller (there may be some specific instances where this does not happen, but those are special circumstances).

The change is predictable according to the formula for thermal expansion/contraction. If the process is controlled and the casting always ejects at the same temperature, then it will always cool the same and the dimensions will be consistent and repeatable.

**Dimensional problems and contraction/expansion**

A dimensional problem can occur when one half of the die is much hotter than the other half. This can be a problem for the die and the casting. For example, if the stationary die half is a lot hotter than the moving half, the guide pins will not line up with the bushings. If a casting is ejected when one half of the casting is considerably hotter than the other half, one half of the casting will contract more than the other half. This will cause the casting to warp and bend.

Many times the condition of the die is responsible for a dimensional failure.

**Flash buildup**

Flash buildup at the parting line can cause several problems.

- It prevents the die from closing properly and dimensions across the parting line could be longer or thicker, depending on the amount of flash.
- It may cause an oversize dimension.
- If the die has a slide that is to be held in position with a wedgelock, the buildup prevents the wedgelock from holding the slide in place, and the slide can back out causing further dimensional problems.

A similar circumstance may be the buildup of flash in front of a slide. This could prevent the slide from going to the “ready to cast” position and hold the die open.

**Soldering**

Small core pins can be very susceptible to this type of problem. Often the size tolerance for features on small cores, less than 1/4 in. (6.2 mm) in diameter, may only be 0.003-0.004 in. (0.076-0.102 mm). In these cases solder buildup and the associated roughness and dragging can cause an oversize out-of-tolerance condition.

Another place soldering and related dimensional problems may occur is walls. If, in a particular area, impingement and soldering are a problem at a wall, the surface roughness may be so great that the missing material could cause an undersize or thin wall.
Force of Injection
If the force of injection overcomes the locking capability of the die cast machine, the tie bars will stretch and allow the die to flash. This flashing will add to the size of the across parting line dimensions and could also cause slides to backout.

The force of injection at the end of the shot is a combination of normal injection force, impact, and intensification. Of these three, impact can be most troublesome since many machines have no way to control it.

Impact is the force generated when a mass comes to an abrupt halt. In the case of the shot end, the mass is the shot piston, coupling, rod and plunger and hydraulic oil that is propelling the shot. The faster that this mass slows at the end of cavity filling, the higher the impact will be.

To reduce impact, you need to try to reduce the mass and speed of the injection system. Using the minimum possible shot speed that makes an acceptable casting is a good way to start. Reducing the mass of the system is usually beyond the capabilities of the operator.

The hydraulic pressure of the machine, the shot cylinder size and the plunger size determines injection force. The larger the plunger, the smaller the alloy pressure will be and the smaller the injection force.
To minimize impact, choose the largest suitable plunger and lowest hydraulic pressure. In most cases, these are decisions that are made by engineering when the process is setup. Your feedback to engineering may be helpful.

The final factor influencing impact is intensification. Intensification is the multiplying or intensifying of the alloy pressure. Typical multiplication is 2 to 4 times. When intensification is applied and how rapidly it builds up to maximum pressure are controls that the operator may be responsible for. Intensification needs to be applied before the gates freeze, otherwise you will be unable to get more alloy into the cavity to feed solidification shrinkage. Also, this pressure is needed to squeeze gaseous porosity as small as possible.

Statistical Dimensional Control
Many manufacturing processes result in a fairly steady dimensional drift. The dimension being produced, say a diameter produced by a turning operation, will gradually get larger (or smaller) as the critical variable changes. In a turning operation, the variation is usually caused by wear of the tool bit. Such processes can be controlled by standard, statistical quality control methods like average and range charting of small sample data.

It has been learned that the die casting process also lends itself to control by statistical process control techniques. As early as the late 1950’s, average and range chart plotting was used as a control technique to maintain minimum pull-out strength of wires cast into a zinc die cast brushes to read IBM punch cards.

In this case, alloy and die temperatures were important process variables. The major difficulty in controlling the die casting process is determining what variables are important and at what levels they must be controlled. These techniques can be expanded to control dimensions also. The process variables that contribute to the dimensional variation need to be identified and then a control technique, such as the average and range chart, needs to be applied.
Summary

There are three categories of defects: surface, internal, and dimensional. Within each category, there are many defects, each caused by something different. Some are within the operator’s control, others are not.

There are two subcategories of surface defects: flow and other. There are many types of flow defects. These result from how the metal flows to and within the die. They may be related to die temperature, alloy temperature, the casting’s geometry, etc.

There are two subcategories of internal defects: inclusions and porosity. Inclusions are when something is included in the metal that shouldn’t be there. Porosity is a void in the casting either caused by trapped gas or shrinkage.

Dimensional defects are related to die temperatures, die condition, and the injection force. Die temperature is the most important variable related to dimensional precision.
Introduction
Work in the die casting plant has specific hazards associated with it. By being aware of these hazards, they can be avoided, ensuring a safe work environment without accident or injury.

Obvious hazards are liquid metal and large powerful machines. Types of hazards in the die casting workplace, personal protective equipment and compressed air safety are all topics discussed in this chapter.

After completing this chapter, you will be able to:
◊ Correctly identify personal protective equipment.
◊ List eight hazards in the die casting workplace.
◊ List seven steps to safely use compressed air.
◊ List six steps to safe handling of castings.

The information presented in this chapter is necessary in order work safely in the die casting workplace.

In the previous chapters you learned about the die casting (DC) manufacturing process. In this chapter you will learn about some of the hazards associated with the DC process and learn to work safely in that environment.

Safety in the Workplace
Any industrial environment has hazards in it. The die casting plant has specific hazards that you must be aware of to work safely. The die casting plant uses molten metal at very high pressures. This requires that you should be thinking about safety, whatever you are doing.

Safety is an attitude: a defensive attitude. Safety in a plant is similar to safety when driving a car. You have to anticipate what will happen when you take an action; in fact, you should be certain of the outcome before any action is taken. You also have to anticipate the actions of others.

The pursuit of safety requires that top management must be fully committed to safety. The company must provide well-maintained and properly guarded equipment in a clean working environment. Supervisors and production personnel must work together to teach and motivate safe work attitudes and habits. If an accident occurs, an objective analysis must be made to determine its cause and avoid its repetition.
The types of hazards that occur in the die casting plant can be characterized as pinch, snag, strike, burn, electric shock, pierce, slip-fall, trip-fall and fire.

These hazards are not unique to the die casting plant, however. As with any activity that has special safety requirements, such as driving a car, you must become familiar with the potential safety hazards in order to avoid injury to yourself or an associate.

**Personal Protection**
For your personal protection it is important to wear the proper protective clothing and accessories.

Because of the hazards associated with liquid metals, high pressures, and high temperatures, it is important to “cover up”. Cotton or woolen clothing is appropriate as opposed to polyester or synthetic materials that will melt under conditions of high temperature.

A die casting machine operator should always wear protective clothing.

◊ Shirts with long sleeves, buttoned at the wrist
◊ Long pants
◊ Molder’s boots
  Molder’s boots have an elastic closure around the ankle that prevents metal from getting into the shoe. The elastic top also makes them easy to put on and remove. These boots should also have steel toes and arch supports.
◊ Gloves
◊ Safety glasses
  Safety glasses with side shields are required in the presence of potentially splashing liquid metal.

Some plants require helmets in order to prevent head injuries.

Figure 9-1 - Properly attired die cast machine operator.
Other jobs in the die cast plant require special protective clothing.

◊ The furnace cleaner has to wear special clothing to protect from radiant heat given off by the furnace. Radiant heat burns faster than the sun burns an unprotected sunbather.
◊ The metal handler has to wear special protective clothing to protect against metal splashing.
◊ Anyone handling metal should wear a face shield. This includes machine operators skimming dross off the surface.

Noise
Excessive noise can be a hazard that can result in hearing loss. OSHA has published regulations regarding noise levels in the industrial environment. Modern machines and equipment are built to meet these regulations. However, the combination of noises in the industrial workplace make it prudent to use hearing protection. At minimum, ear-plugs are recommended and are usually readily available. Hearing protection is required in some plants.

Die Casting Machine Safety
The die casting machine has moving parts, pinch and shear points, lubricants, hydraulic fluid, and electrical controls. Particular areas of the machine may be hot; the hydraulic fluid could be hot.

The NADCA course “Die Casting Machine Safety” is specifically written to deal with the DCM safety. Because safety is so important and detailed, all persons working in the DCM environment should study it carefully.

The die casting die is hot at operating temperatures, and can have pinch and shear points. Each die feature that is a recognized potential hazard is discussed in the Chapter 5: Die Casting Die along with appropriate preventative measures.

Auxiliary equipment such as furnaces, conveyors, reciprocators, robots and the like have specific safety considerations. These are discussed in detail in other NADCA courses or lessons that are appropriate to them.
Trip-fall hazards
The work area also requires special safety considerations. Keeping your work area neat and clean is the first step to a safe environment and maintaining your personal safety.
- Tripping obstacles can cause injury.
- Machines will have components that project from them. These are trip-fall hazards. These items should be painted with standard OSHA color coding in order to make them more visible.

![Figure 9-3 - Trip obstacle projecting from the DCM control cabinet.](image)

Slip-fall hazards
The die casting process consumes a large amount of lubricants, release and cooling agents. These often get on the floor and cause a slip-fall hazard. Good housekeeping practices must be maintained to keep floors clean. When liquid spills occur, surface-drying compounds should be used immediately. Rigid equipment maintenance and preventative programs should be used to minimize the leakage of fluids from machines and dies.

![Figure 9-4 - Spilled fluid causing hazardous floor conditions.](image)  
![Figure 9-5 - Sprues and overflows creating floor clutter.](image)

Floor clutter
Floor clutter creates slip-fall hazards. This includes electric cords, cables, and hoses running across the floor. If hoses, pipes and cables must be at approximately floor level, they should be in a trench that is properly covered. Floor clutter could also include process debris such as scrap, biscuits, runners, overflows, and sprues.
Operator platforms
Operator platforms are used to establish the proper working height and prevent fatigue. The platforms should be of uniform height for similar machines. The platforms need to provide a non-skid surface to minimize any slip-fall hazard. Proper working heights are necessary to minimize pains that result when a person works in an awkward position.

Machine controls
Machine controls must also be at the proper height to avoid fatigue. A maximum height of 70 inches (1.78 m) to the top of the operator control panel has been determined satisfactory.

Plant air or high-pressure air is used in a variety of ways in the die casting operation. If improperly used, it can be hazardous.

- Escaping air can be noisy and an air blast can carry small particles of dirt or metal. This could be hazardous to your hearing or eyesight.
- Air connections should be secured by strong couplings and connectors to prevent leakage or sudden air blasts.
- Air hoses should be arranged to prevent tripping hazards.

Many actions can be taken to prevent accidents when working with high-pressure air.

- Check all air hose connections before turning on the air/pressurizing the lines.
- When turning air on or off, hold the nozzle end of the hose to prevent whipping of the air line.
- Shut off the air before adjusting air tools.
- Never point an air nozzle at anyone.
- Do not use air to dust off hair or clothing, or to sweep the floor.
- Wear safety glasses when using high-pressure air.
- Inspect air hoses regularly and request prompt repair of defective lines.
Material Handling
Handling materials can also be injurious. Correct handling of objects in the die casting plant is important. The following pointers to the correct procedure for handing various materials should be observed. This is not a comprehensive list, but a starting point.

◊ Inspect materials for slivers, jagged or slippery edges, and burrs.
◊ Keep fingers away from pinch points, especially when setting materials down.
◊ When handling long objects such as pipes and panels, keep hands away from the ends to prevent pinching hands.
◊ Wipe off greasy, wet, slippery or dirty objects before trying to handle them.
◊ Keep hands free of oil and grease.

Working with liquid metals can be hazardous. The burn hazard from the liquid metal or hot casting is obvious. In the die casting plant, one always has to pay attention to what is touched. Many surfaces may be hot, and not necessarily marked or otherwise indicated.

Explosion
With liquid metal, there is even a greater hazard than burns, EXPLOSION! If any liquid containing water gets under the surface of the liquid metal, the water will turn to steam, causing the metal to explode and spray out of the furnace. This could cause the door or a wall of a furnace to blow out causing serious injury to any nearby personnel.

When water turns to steam, it rapidly expands to 1600 times its volume. One drop of water will create 1600 drops of steam. This is what causes the metal to erupt from the furnace. If enough water is available, the eruption will be so violent and so fast that the liquid metal will be turned into a fine particle spray (dust). This can result in a secondary explosion, even more violent than the first. The secondary explosion is a dust explosion in which the fine particles burn up. In the case of an aluminum furnace, this can be quite devastating. When a pound of aluminum burns up it releases three times the energy of a pound of TNT.

Nothing wet should ever be charged under the surface of molten metal. All tools to be used in the furnace must be coated and preheated prior to use. All ingots or scrap should be stored in a dry place and preheated prior to charging into the furnace.

Figure 9-7 - Moisture trapped in the shrink crack on top of an aluminum sow caused the center of the sow to be blown out.

Figure 9-8 - As a result of water trapped under the liquid aluminum surface, a furnace building was leveled.
Industry Safety Perspective
Statistics from OSHA indicate an incidence rate for lost work injuries in non-ferrous die casting at 4.3 per 100 workers, and 1.7 per 100 workers for all industrial injuries and illnesses.

Obviously, there is a lot of room for improvement.

NADCA has taken the lead in this industry to promote a safe workplace. NADCA:
◊ Promotes a safe workplace through annual recognition of members that have had injury-free locations.
◊ Promotes safety through presentation of DCM safety classes, publications and videos.

Summary
There are many hazards associated with working in a die casting plant. It’s essential to understand the hazards in order to avoid them and ensure a safe working environment.

Safety is a defensive attitude. It requires commitment from top management down.
◊ Personal protective clothing and accessories helps minimize your risk to certain hazards.
◊ The die casting machine has several places that can cause injury, including hot dies, and pinch and shear points.
◊ There are several types of work environment hazards, too. Cords, hoses, floor clutter, and obstacles can create safety issues.
◊ High pressure air can be hazardous if improperly used. Always follow the safety guidelines when using high pressure air.
◊ Correct handling of objects in the die casting plant is important. Always follow the safety guidelines when handling materials.
◊ Working with liquid metals can be dangerous, as they can explode if any water is mixed into the melted metal.
Costs in the die casting plant come from a variety of sources.

There is the cost of machinery and equipment, of labor, of materials, of utilities. The cost of management, supplies, real estate, taxes and the list seems to go on and on. In this chapter you will learn about the costs of the DC manufacturing process and a method for identifying those costs.

After completing this chapter, you will be able to:

◊ Identify the highest cost factors in the die casting industry.
◊ Identify the three levels of a manufacturing cost system.
◊ Explain the difference between direct and tare material in a die casting.

The information presented in this chapter provides background information on costs in the die casting industry. This will aid in understanding how casting costs are developed and how savings could possibly be achieved.

In the previous chapters you learned about the die casting (DC) manufacturing process. In this chapter you will learn about some of the costs associated with the DC manufacturing process.

The following new term is used in this chapter.

Operations Traditionally used to identify steps that add value or transform the product.

Cost Factors
All the costs, plus a profit, have to be included in the selling price of the castings. Conventional wisdom about die casting costs indicates the highest cost factor is material, followed by labor and then energy. Others argue that the equipment is the highest cost factor because it is so expensive. For example, the cost of installing a new 600-ton DCM and ancillary equipment to complete a work cell could easily be $1.25 million.

In this chapter we will look at a multi-level system for determining cost in the die casting industry through the use of several examples. The levels investigated will be the Factory level, the Work Cell level, and the Product level.
The idea that the highest cost item is alloy may come from the person that signs the checks that go to vendors. The largest and most frequent checks usually go to the alloy suppliers. So the perception is that the cost of alloy is the highest cost factor in the die casting operation.

This may or may not be true; it all depends on the type of casting operation. For example, specialty producers of miniature zinc castings make thousands of castings per hour, but many of the castings only weigh grams. The amount of alloy going through the plant on a daily base could be less than a ton. In this case, alloy may be a small cost.

Factory Level Costs
To determine material cost, an example will be used that tries to identify all the costs associated with the alloy in a particular casting. The example is a 5.5 pound 380 aluminum die casting produced by a custom die caster. The published price of 380 aluminum is $0.80 per pound.

Material Cost
Direct costs:  5.50 lb/piece x $0.80/lb. = $4.40/piece

In metal melting, material is lost to oxidation every time it is melted. In our example, oxidation losses in melting are 5%. In other words, 5.79 pounds of alloy must be melted to provide the 5.5 pounds required for the casting.

◊  5.50 lbs. * 0.95 = 5.798 lbs.

Melt loss costs $0.2316 per casting.

◊  (5.79 – 5.50)lbs. x $0.80/lb. = $0.2319

A proper melt loss study is useful for determining exactly how much metal is being lost during the melting process. Vendor melt loss rates are for optimal melting processes, which are rarely obtainable in a die casting facility. This study must weigh the amount of metal coming out of furnace versus the metal originally charged. Although oxidation accounts for a majority of melt loss, it does not account for all of it.

Other added costs: There are other costs associated with the material. The “real” material cost is greater than the market price of the alloy. The difference is caused by the time value of money (interest) and storage and handling costs incurred by the manufacturing organization in getting the raw material to the die casting machine.

Storage costs: Suppose that the raw material buyer has an opportunity to purchase 380 alloy at $0.75 per pound, but he must buy a 3 months supply. A month’s requirement is 10,000 pieces. The quantity of material purchased is 165,000 pounds at a cost of $123,750.

◊  10,000 pieces/month x 5.5 lbs./piece x 3 months = 165,000 lbs.
◊  $0.75/lb. x 165,000 lbs. = $123,750

When materials are purchased, they are usually quoted FOB (freight on board) the vendor’s plant. This means that shipping is the responsibility of the die caster. In this example, the shipping cost is $500.00 and the paperwork cost associated with the purchase is $200.00. Purchasing and shipping will add another $0.004 per pound.

◊  ($500.00 + $200.00) ÷ 165,000 lbs. = $0.0042/lb.

Since the material will not be consumed for 3 months, the average value of inventory will be one half of the material purchase price or, $61,875.00.

◊  $123,750 ÷ 2 = $61,875.00
This value is not free, the yearly cost of that much inventory at 10% annual interest would be $6,187.50, or the three-month cost would be one-fourth of it, $1,546.88. This adds $0.009/lb.

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<th>Result</th>
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<tr>
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<tr>
<td>$6,187.50 \div 4</td>
<td>$1,546.88</td>
</tr>
<tr>
<td>$1,546.88 \div 165,000 lbs.</td>
<td>$0.0094/lb.</td>
</tr>
</tbody>
</table>

*(10% annual interest)

The material must be stored for three months. Alloy should be stored in a dry environment, without excessive temperature variation that could cause condensation.

When the material is first brought in, it requires 300 square feet of floor space. It is consumed in three months, so the average floor space required is 150 square feet. The cost of indoor storage is assumed to be $23.50 per square foot per year. The storage costs add $0.005 per pound.

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 sq. ft. * $23.50 =</td>
<td>$0.0053/lb.</td>
</tr>
<tr>
<td>165,000 lbs. * 3 months</td>
<td></td>
</tr>
<tr>
<td>12 months/yr.</td>
<td></td>
</tr>
</tbody>
</table>

Handling costs: Finally, there are handling costs associated with delivering the alloy to the storage area and melting furnace. Assume that it took the forklift driver an hour to unload the alloy and deliver it to the storage area. Also assume the alloy is delivered to the combination melter/holder at the die casting machine in 2000 lb. increments, each delivery from the storage area requiring 15 minutes. If the forklift driver cost is $30.00 per hour, then the additional cost for handling is $0.004 per pound.

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 hr. + 165,000 lbs. / 2,000 lbs./del</td>
<td>21.625 hr.</td>
</tr>
<tr>
<td>15 min./del. / 60 min./hr.</td>
<td></td>
</tr>
</tbody>
</table>

Delivery time:

Cost of deliveries:

$648.75

Delivery cost per pound of alloy:

$0.0039/lb.

Total material cost: Now, the total cost of material as it arrives at the die cast machine is $0.7727 per pound. This adds 2.8% additional cost.

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost (per lb.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchased price</td>
<td>$0.7500</td>
</tr>
<tr>
<td>Purchase and shipping</td>
<td>$0.0042</td>
</tr>
<tr>
<td>Inventory interest cost</td>
<td>$0.0094</td>
</tr>
<tr>
<td>Storage</td>
<td>$0.0053</td>
</tr>
<tr>
<td>Handling</td>
<td>$0.0039</td>
</tr>
<tr>
<td>Total</td>
<td>$0.7728</td>
</tr>
</tbody>
</table>
With die casting, there is the casting, the direct material, and the additional material used that is a byproduct of creating the casting. This includes; biscuits or sprues, runners, overflows, flash, machining stock.

For purposes of description here, this material is referred to as tare. In most manufacturing plants, this is called “offal”, “machining scrap”, “remelt”, “trimmings” or any other appropriate term. Much of this material is reclaimed, but some is scrapped outright. The costs associated with this material must be recovered.

The amount of this material is specific to each die casting die, so costs should be established at the tool level. The following example uses the same 5.5 pound 380 aluminum casting used before to identify the tare material costs. The shot weight required to make this casting is 8.0 pounds. This means the runner, overflows and vents consume 2.5 pounds of alloy. This is a yield of 69%. Yield is material shipped divided by material cast times 100%.

\[ \frac{(5.5 \text{ lbs.} \div 8.0 \text{ lbs.}) \times 100\%}{100\%} = 69\% \]

The excess 2.5 pounds of material must be removed from the shot and can be remelted and reclaimed. The costs associated with this material are the cost of removal and disposal. This removal is not the trimming operation (the actual trimming operation is a work cell cost, more about that later), but the cost of collecting the material and returning it to the remelt furnace. If this is done manually, someone has to be assigned to collect the “offal” and transport it back to the furnace. This material could also be collected by conveyors and transported to the furnace in a mechanized fashion.

In this example, the assumption is made that there is a conveyor system for scrap collection and transport. The return on investment for the conveyor system is assumed to be $0.005 per pound. Another material loss occurs when the “offal” is remelted. Each time the material is melted, some is oxidized and lost. In our example, melt losses are 5%.

The material cost for the tare is:
- Collecting and returning to remelt: $0.0125
- Lost material make-up: $0.0966

Adding the direct material and tare together for the casting in our example yields a cost of $4.584.

\[ \begin{align*}
\diamond & \text{Casting material} \\
& - 5.79 \text{ lbs.} \times \$0.7728/\text{lb.} = \$4.4745 \\
\diamond & \text{Offal cost} \\
& - \$0.0125 + \$0.0966 = \$0.1091 \\
\diamond & \text{Total material cost} = \$4.5836
\end{align*} \]

This example shows one method that can be used to determine the material cost for a particular casting. Significant in the example is the melt loss; it amounts to $0.3258 per casting or 7% of the total material cost. The direct material cost is an example of a factory wide cost for 380 alloy. The tare material is a product cost based on the factory cost for the alloy and a particular tool required to die cast the product.
Work Cell Level Costs
A work cell is a grouping of machines that performs operations sequentially to a piece part. Regardless of how much time each operation takes, the piece part will take the same amount of time at each machine, i.e. the longest operation will determine the pace of piece parts going through the work cell.

Figure 10-1 - The five machines diagrammed are connected in series with an automated parts transfer mechanism. Any workpiece entering the first must pass through all five whether the remaining four machines work on it or not. Since a workpiece in one machine must utilize all five, this system is a single work cell.

The work cell is comprised of five elements:
◦ A processing machine (or facility)
◦ Provisions for introducing the workpieces to the processing machine
◦ Provisions for extracting the workpieces from the processing machine
◦ An operator or controller
◦ Floorspace

Figure 10-2 - Work cell map.

Any workpiece passing through a work cell has value added by the work cell. An appropriate share of operating costs of the work cell must be applied to the workpiece. The costs of the work cell must be defined in such a way that those costs can be readily identified. These costs can be classified as:
◦ Cost per idle hour.
  Cost per idle hour is costs incurred whether the work cell is operating or not. These are fixed costs. This includes floorspace, return on investment, and fixed maintenance costs.
◦ Cost per operating hour.
◦ Extra cost per piece.
Background information
Here’s some background information regarding the workcell required to create our example 5.5 pound casting.

◊ Fully automated 600T DCM with furnace, auto ladle, reciprocator, plunger lube, detectors, quench tank, trim press and robot.
◊ An investment of $1.25 million; expected to return 20% annually.
◊ Requires 900 sq.ft. of floor space in a high bay area of the die casting plant. Floor space in this area of the plant costs $30.00 per square foot per year.
◊ Expected to run 50 weeks per year, 80 hours per week, at a utilization of 80%, or 3200 hours per year.
◊ Casting runs at a production rate of 50 pieces per hour.
◊ Fixed maintenance costs are 5% of the return on investment.

The cost of floor space is $27,000 per year or $8.4375 per hour.

$30.00/sq.ft./yr. x 900 sq.ft. = $27,000.00/yr.
$27,000/yr. ÷ 3200 hrs./yr. = $8.4375/hr.

The cost for the ROI (return on investment) is $78.125 per hour.

$1,250,000 x 0.20 = $250,000./yr.
$250,000 ÷ 3200 hrs. = $78.1250 / hr.

The cost of fixed maintenance is $3.9062 per hour.

$250,000 x 0.05 = $12,500
$12,500 ÷ 3200 hrs. = $3.9062/hr.

The total cost per idle hour is:

<table>
<thead>
<tr>
<th>Floorspace cost</th>
<th>$8.4375/hr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROI cost</td>
<td>$78.1250/hr.</td>
</tr>
<tr>
<td>Fixed maintenance cost</td>
<td>$3.9062/hr.</td>
</tr>
<tr>
<td>Total cost</td>
<td>$90.4682/hr.</td>
</tr>
</tbody>
</table>

$90.468 represents the hourly fixed cost of the workcell based on a 3200 hour annual load. When the workcell operates fewer than 3200 hours, each hour less than 3200 hours represents $90.468 of unrecoverable money. These costs are called “underapplied” since they cannot be applied to any specific product. Each hour over the 3200 hours represents a gain of $90.468, or an “overapplied” cost. This represents money earned for costs that were never incurred.

Costs per operating hour are the additional costs when the work cell is operating. These include utilities, services, and maintenance. Our example work cell has the following utility costs:

<table>
<thead>
<tr>
<th>Electricity = $0.06/kw./hr</th>
<th>Steam = $0.24/lb.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressed air = $0.022/cu.ft.</td>
<td>Water and sewer = $0.30/gal.</td>
</tr>
</tbody>
</table>
When the cell is operating it uses the following utilities:

<table>
<thead>
<tr>
<th>Service</th>
<th>Rate</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>50 Kw/hr x $0.06/Kw/hr</td>
<td>$3.00/hr.</td>
</tr>
<tr>
<td>Compressed air</td>
<td>2 cu. ft/hr x $0.022/cu.ft.</td>
<td>$0.05/hr.</td>
</tr>
<tr>
<td>Water and sewer</td>
<td>5 gal/hr x $0.30/gal.</td>
<td>$1.50/hr.</td>
</tr>
<tr>
<td>Total utilities</td>
<td></td>
<td>$4.55/hr.</td>
</tr>
</tbody>
</table>

Services are functions that the work cell cannot do for itself, so they must be purchased. These services include time-keeping, purchasing, material management, shipping, material handling, engineering and training. In this example, it is assumed that services cost $10,000/yr or $3.125/hr.

Maintenance is the physical care and repair of equipment and facilities within the work cell. Each work cell must literally buy all maintenance. Assume the maintenance costs for this DCM workcell are planned at $7,500 per year, or $2.3438 per hour for the 3200 hour year.

The total of utilities, services and maintenance is $10.019 per hour.

<table>
<thead>
<tr>
<th>Total utilities</th>
<th>$4.55/hr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Services</td>
<td>$3.125/hr.</td>
</tr>
<tr>
<td>Maintenance</td>
<td>$2.344/hr.</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$10.019/hr.</strong></td>
</tr>
</tbody>
</table>

When the $10.019 is added to the fixed cost of $90.468, a $100.487 per hour operating cost results.

Some activities in the operating factory cannot be applied to specific functions because of their general or variable nature. These are called “overhead” or “burden”. Examples are accounting or legal activities and salaries of the plant manager or controller. Other costs included as general burden are the “overapplied” or “underapplied” cost previously discussed.

The business must pay this burden. The question becomes, “How can or should it be distributed?” Distributing it over all direct labor hours is a common accounting practice. Direct labor hours are hours of labor that added value to the product.

In this example, the factory has a general burden of $500,000. This factory has 200 direct labor employees, each working 1760 hours per year for a total of 352,000 direct labor hours. The cost of the general burden is $1.42/hour.

If the factory were fully automated, the general burden functions would still be there. The general burden would then have to be applied to the automation equipment. If work cells provide all the added value to the products, then the general burden could be applied to the work cells.

To do this, start by estimating the work cell costs to operate the cell for the next year. The general burden could then be expressed as a percentage of the total estimated cost. For this example the estimated cell costs for the next year are $10,000,000. This percentage is 5%.

\[\frac{500,000}{10,000,000} \times 100\% = 5\%\]
This percentage, 5%, is then added to the raw operating cost of the cell, for a total hourly cost of $105.51.

\[ 1.05 \times 100.487 = 105.51 \]

If 50 castings per hour were produced, the cost per casting would be $2.1102. This is the work cell cost for the casting.

\[ \frac{105.51}{hour} \div \frac{50 \text{ castings}}{hour} = 2.1102/\text{casting} \]

**Product Level Costs**

The preceding sections showed how costs associated with material and a work cell are reduced to a “charging” rate for that activity. When work cells were discussed, an activity that added value to the product was used as an example.

There is another type of work cell called a “service” cell that performs activities that do not actually change the product or add value but do add cost to the product. A service cell could be the toolroom, maintenance or a conveyor.

The computed costs of all products manufactured must include the costs of all the cells. The charging rates of the various cells are used to establish product cost.

A product tree consists of many materials and/or items brought together to make one product. That product is in turn used in many other products. The original materials and items are like the root system of the tree; the basic product is like the trunk of the tree; and the many final products are the branches.

Many consumer product trees may be more like the Banyan tree, where there are many trunks supported by a root structure and spreading into a single but extensive and complex branch structure. Each root, trunk, and branch must be clearly identified as an individual item. Then the cost of each individual item must be established.

A simple product line is shown in Figure 10-3. There are two product types, X and Y. Each type has a large and small version and each version has a plain or deluxe model. There are a total of eight products. Each product must have its own cost summary. No single component is used in all products; some of the components may be used in other products.

<table>
<thead>
<tr>
<th>Component</th>
<th>Type X</th>
<th>Type Y</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small</td>
<td>Large</td>
</tr>
<tr>
<td>AL</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>AS</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>BP</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>BC</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>CX</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>CY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>H</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

*Figure 10.3 - The hypothetical product line used for an example has a parts breakdown as shown in this table.*
To determine a product tree, each unique product that is sold to a customer must be identified. In the example, each of the eight products is unique. Then for each unique product, the items, components, and/or materials that are used to make it must be listed. Each column in Figure 10-3 is such a list. The list must show how many or how much of each item is used. Figure 10-4 shows the cost of each unique component and Figure 10-5 shows the cost for each product.

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
<th>Component</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>AL</td>
<td>$95.00</td>
<td>CX</td>
<td>$8.50</td>
</tr>
<tr>
<td>AS</td>
<td>$85.00</td>
<td>CY</td>
<td>$12.88</td>
</tr>
<tr>
<td>BP</td>
<td>$0.01</td>
<td>N</td>
<td>$3.00</td>
</tr>
<tr>
<td>BC</td>
<td>$0.10</td>
<td>D</td>
<td>$5.00</td>
</tr>
<tr>
<td>N</td>
<td>$4.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 10-4 - This chart shows the cost of individual components from which the X and Y products are made.

<table>
<thead>
<tr>
<th>Type X Product</th>
<th>Small</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>D</td>
<td>P</td>
</tr>
<tr>
<td>$96.75</td>
<td>$98.10</td>
<td>$106.80</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type Y Product</th>
<th>Small</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>D</td>
<td>P</td>
</tr>
<tr>
<td>$117.80</td>
<td>$118.08</td>
<td>$127.23</td>
</tr>
</tbody>
</table>

Figure 10-5 - The total cost of components used in each of the X and Y products.

When the product tree is complete, the manufacturing steps for each item must be identified and listed. These steps are usually called operations. Since the work of service cells must also be included, the term “steps” will be used in place of operations in this example.

A simple example of itemized manufacturing steps could be the assembly of the small plain Type X product from Figure 10-3 as follows:

Using work cell B-10, place one item “AS” into holding fixture and place one item “CX” in position on item “AX”. Secure “CX” to “AS” with 23 “BP” screws. Use pneumatic screwdriver to secure “BP” screws. Then position one item “N” in position on item “CX” and secure with two “BP” screws. Place assembly into shipping rack, 48 to each rack, and stack the racks 10 high.

Salvage repair one part of every 101 parts assembled.

Fork truck move one stack of 10 racks (480 assemblies) to the warehouse.

Once each month remove 4800 assemblies (10 stacks of 10 racks per stack) from the warehouse and ship to the customer.