THE EAGLE GROUP

INVESTMENT CASTING

Process Guide

A comprehensive introduction to investment casting

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1. Introduction

Dear Reader,

Investment casting, or "Lost Wax" casting, as it's often known, is one of the oldest forms of casting in existence. It's also one of the most versatile and widely used casting methods today. Over thousands of years, the techniques of investment casting have changed very little, but the science behind the process–along with the equipment used–has allowed the industry to continually innovate.

Today, investment casting is an excellent choice for a broad range of products. Nearly any alloy can be cast using this process, so the perfect balance of strength, weight and cost can always be found. Perhaps most importantly, investment casting allows for intricate shapes and complex inner cavities that cannot be achieved through other casting methods. Many parts that would otherwise have to be fabricated or machined can be efficiently molded through investment casting.

Of course, there are times when investment casting is not the ideal process. Comparatively high labor costs and setup costs can make other casting processes a better fit in some cases. Furthermore, not every product needs the accurate dimensions, tight tolerances and smooth surface finish offered by investment casting.

The purpose of this guide is to illustrate the history and current practice of investment casting, and to suggest a few of the possibilities afforded by the process.

If you're bringing a new product to market, or moving to a new manufacturing process, feel free to consult me with any questions you might have about investment casting, or metal casting in general.

Sincerely,

Debbie Pipoly
President
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2. Background & History

5,000 Years in the Making, Investment Is Still One of Today's Top Metal Casting Methods

Investment Casting is nearly as old as metal casting itself, with the earliest known examples dating back to 3,500 BC.[1] Before investment casting was invented, metal castings were created using open stone or ceramic molds. Investment casting allowed for much greater detail and smoother finish, vastly expanding the possibilities of metal casting.

Lost Wax Casting

The earliest investment casting process involved shaping a pattern out of beeswax, a malleable material that could be rendered in high levels of detail. The beeswax pattern was then covered in clay, and the clay-wax combination was placed in a furnace, both to harden the clay and melt out the wax. Molten metal could then be poured into the clay shell, and allowed to harden into a detailed, smooth-surfaced casting. The process was known as "**lost wax casting**," as it is still called in many regions.

Investment Casting as Art

A wide range of civilizations, from the Ancient Greeks to the Scythians, innovated the process of investment casting to fit their purposes. For much of history, investment casting was predominately used to produce jewelry and artwork. **Ancient Egyptians** cast jewelry and gold figurines depicting pharaohs and gods. During the Middle Ages, **Viking and Anglo-Saxon** goldsmiths perfected a unique style of highly ornamental jewelry worn throughout Europe. During the Italian Renaissance, artists began casting life-size figures out of bronze and gold.

> **Lost wax casting** got its name because early methods used a porous investment shell, which absorbed the wax when heated.

> The "investment" in investment casting refers to the process of coating the wax pattern in ceramic slurry. **"Investing"** is any process in which an object is dipped into liquid, and a layer of the liquid attaches itself to the object.

Mechanization of Investment Casting

Despite millennia of innovation, industrial applications of investment casting were not popularized until the early 20th century. At that time, investment casting was most often used by goldsmiths to produce unique, extravagant pieces of jewelry. But an inventive Chicago dentist by the name of W.H. Taggart developed a gas-pressure apparatus to systematize production of gold dental inlays.[2]

For most of the 20th century, other metal casting techniques dominated industrial applications. During World War II, however, the defense industry's high demand for parts overwhelmed casting facilities using other methods. Furthermore, new inventions like jet propulsion systems called for high-melting-point metals that were not machinable. Through investment casting, manufacturers were able to produce **near-net-shape parts** that required little or no machining, and could be produced using almost any alloy. Through the end of the war, investment casting was the method of choice for production of aircraft parts, ammunition and other products that required durability and high levels of detail.[3]

Near net shape refers to a product that requires little or no finishing before it is put into use. Investment casting was originally popularized during WWII for its ability to produce near-net-shape products.

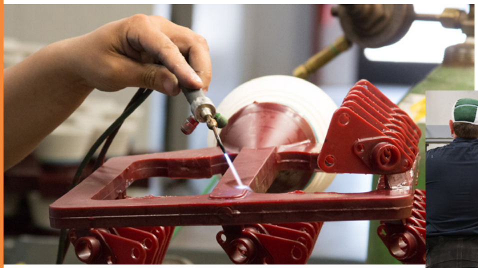
Investment Casting Today

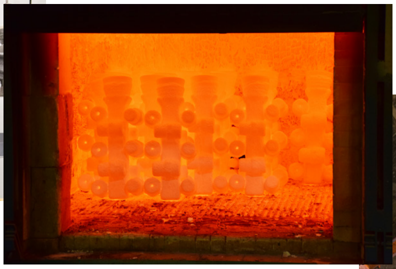
Investment casting is still one of the most accurate and precise forms of metal casting available. The process is used to form castings with greater dimensional accuracy, finer detail and smoother surface finish than most other processes allow.

An operator at Eagle Precision produces wax patterns for investment casting

3. Investment Casting Process

1. Manufacture the Wax-Injection Tooling
2. Produce Wax Patterns
3. Assemble Wax Patterns to Form a Tree
4. Produce the Investment Shell
5. Dewax the Mold
6. Pre-Heat the Mold
7. Pour the Castings
8. Clean the Castings
9. Finish the Castings






1. Manufacture the Wax-Injection Tooling

In ancient times, wax patterns were made from beeswax, often by hand and just one at a time. Today, wax-injection dies are used to create a wax pattern for each casting produced.This tooling is a permanent fixture for each part, and is only replaced if it is damaged or if the design changes. The primary material used for the manufacture of the dies is aluminum, and they are manufactured primarily using CNC machining.

The shape of the die corresponds to a negative relief of the final product, with allowances made for shrinkage of the wax and the material of the final casting. As the wax used for the injection process is non-abrasive, dies can produce hundreds of thousands of shots with minimal maintenance and low risk of damage/replacement of the die.

2. Produce Wax Patterns

Once the wax-injection tooling is ready, pattern wax is brought to a temperature at which it is in a semi-liquid or a paste consistency. In this state, the wax is injected into the wax-injection die to form a wax pattern which is just slightly larger than the final casting being produced (due to shrinkage).

This injection process is repeated as many times as required to produce the number of patterns to fulfill order requirements.

3. Assemble Wax Patterns to Form a Tree

The tree, formed by combining several wax patterns along a common sprue greatly increases the efficiency of the investment casting process. Instead of casting one part at a time, these assemblies allow multiple patterns to go through the remaining steps together.

Assembling a wax pattern tree

After a specified number of wax patterns as been produced, the patterns are affixed to wax bars to form the tree, sometimes referred to as a "cluster." The patterns are attached where the gates are located, which is where the metal will enter the individual casting. The tree must be of adequate size to provide enough feed metal to help provide a sound casting during the metal-solidification process.

The number of patterns assembled to form the tree is one of the primary factors in driving the piece price of the final casting: more patterns per tree can lead to a lower piece price.

4. Product the Investment Shell

The assembled trees are then consecutively dipped in refractory slurries (liquid mixtures of heat-resistant

An Eagle Precision operator coats a tree with fine sand

materials) and coated with different sizes and types of sand, or stucco, to produce a ceramic shell around the wax. As the trees are coated, wax is left exposed at one end to facilitate removal in the following stage.

The first investment coat is critical to produce a superior surface finish, one of the advantages of the investment casting process. The first coat of slurry is applied by submerging the wax tree into a well-mixed vat of zircon-based slurry, with a consistency similar to latex paint. The assembly is then covered with zircon sand, then left to dry. After drying, the assembly is dipped in additional slurries and coated with increasingly coarse fused-silica sands, which are utilized to build mold strength.

Between each slurry/sand coating, the molds are left to dry between 8-24 hours. The mold-building step (producing the investment shell) of the investment casting process requires the greatest amount of time to complete.

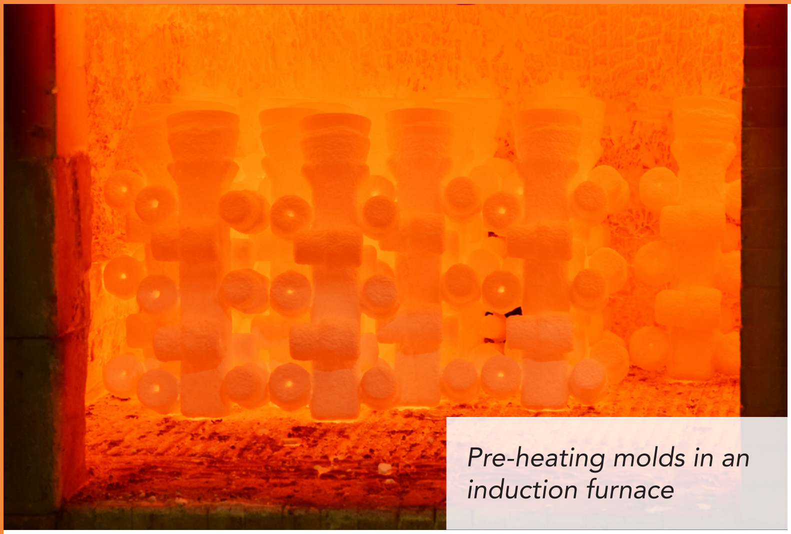
5. DeWax the Mold

The fully coated ceramic mold is now ready to have the wax removed in order to pour the metal into the mold. In order to complete this task, the molds are placed into an autoclave with the wax-exposed end facing downwards. The autoclave is closed, and steam is injected into the autoclave in a matter of seconds which pressurizes the vessel and exposes the molds to temperatures exceeding 300F. The steam heats the wax, and the pressure of the steam is required to offset the pressure of the heating, expanding wax inside of the molds.

An Eagle Precision operator dips a tree in a vat of investment material

As the wax heats, it melts rapidly and drains quickly out of the open end of the mold. Nearly 100% of the wax is captured and recycled for use again in the wax-injection process. After a short time, the molds are removed from the autoclave, and are allowed to cool and dry.

This aspect of the process illustrates the versatility of investment casting. In other casting methods, molds must be opened (usually two sides are connected by a hinge) in order to remove the pattern. In investment casting, the pattern can simply be melted out, allowing for much greater detail in a seamless mold.



Pre-heating molds in an induction furnace

6. Pre-Heat the Mold

The dewaxed ceramic mold is not quite ready to be filled with molten metal; as with any ceramic, it must be fired to bring it to an adequate temperature to accept pouring of molten metal. The molds are loaded into an oven that heats them to 1,900 degrees F and allows them to cure at that temperature for a certain amount of time. This firing process also burn -out any remnants of wax left-behind in the molds, which could cause casting defects.

This additional heating process accomplishes four tasks:

- Ensuring complete removal of pattern wax;
- Strengthening the mold walls;
- Allowing the molten metal to retain its liquidity as it travels through the mold;
- Offering improved dimensional accuracy by allowing the mold and casting to shrink together as they cool.

"Recycled Wax" Casting: Due to improvements in process, wax from patterns is no longer "lost." Instead, a large percentage of melted wax can be collected, purified and re-used in future patterns.

7. Pour the Castings

When the molds have been fired and held at the firing temperature, the metal to be poured is melted and prepared for pouring. Induction furnaces melt the metal by using electricity and magnetism to generate heat, and quickly liquefy metal ingot to temperatures nearing 3,000 degrees F. The chemistry of the metal is confirmed using a spectrometer, and pouring of the molds commences.

Pouring steel into an investment mold

The method used for pouring depends on the material being used, the size of the mold and the facilities present. Variations include: gravity pouring, vacuum pouring, and vacuum pressure casting (VPC). In gravity pouring, the fired molds, still around 1,900 degrees F, are pulled from the ovens and brought to the furnace to be poured. The metal enters the mold cavity quickly, and as the molds are set-aside to cool, the metal inside the molds begins to solidify.

8. Clean the Castings

The now room-temperature castings are "cleaned" by removing the ceramic mold material and sawing or grinding away gates. The once strong ceramic mold has been spent and can be shaken away through vibration and blasting. Individual castings are cut away from the metal tree, and the gates (where the castings were attached to the tree) are removed through grinding operations. The castings are then sand blasted to remove any residual ceramic and to improve the surface finish for inspection.

9. Finish the Castings

The final steps of the investment casting process vary widely from part to part. Most castings receive some sort of heat treatment to improve the material's physical properties. Following heat treatment the castings are again blasted, and final-inspected prior to shipment. Many investment castings are near net-shape or net-shape products, meaning that they are dimensionally accurate enough to require little to know machining. Therefore, detailed gauging and inspection operations are performed prior to shipment to confirm the parts meet all customer requirements.

Above: *Separating castings from a tree with a cutoff saw*

Below, left: *Investment castings cool before their shells are broken away*

Below, right: *a pice of an investment mold, broken away from a casting*

4. Tolerances, Characteristics & Design Recommendations

Investment casting is known for its ability to hold to tight tolerances, and produce parts with excellent surface finish.

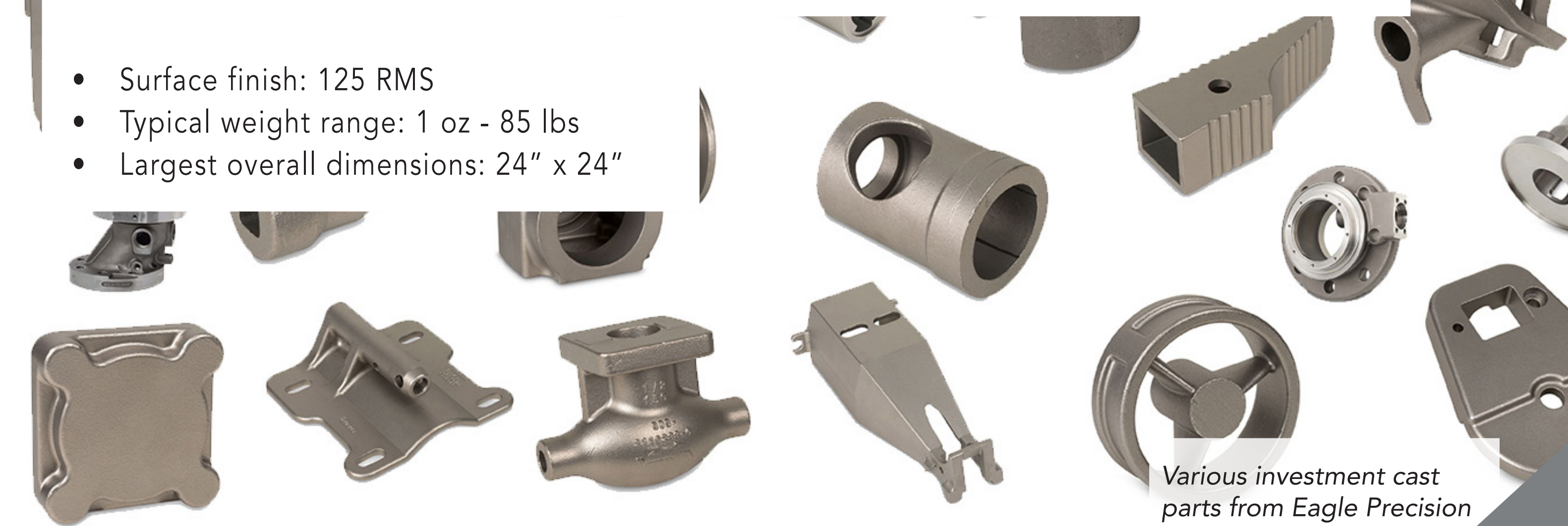
The following tables illustrate various dimensional tolerances, based on the experience of Eagle Precision Cast Parts, Inc., and on standards recognized by the American Foundry Society (AFS).[4]

Dimensional Tolerances

Dimensional stability	+/- .005” per inch
Wall thickness	.030” - .060” for small castings
	.080” - .1” for medium and large castings
Flatness and Straightness	.005” per inch of length
	Heavy sections: add an additional .01”
Raised features (lettering, numbering, logos)	Suggested dimensions: .02” (raised figures in a protective depressed pad)

Investment Casting Characteristics (at Eagle Precision)

- Surface finish: 125 RMS
- Typical weight range: 1 oz - 85 lbs
- Largest overall dimensions: 24” x 24”



Various investment cast parts from Eagle Precision

Design Guidelines

Investment casting foundries can often help design castings that will maximize the gains offered by the casting process. As a customer, the more you know about your product, the better.

Generally, your product should be able to have **large fillet and corner radii**. This reduces stress in the part, and often improves appearance. We recommend that you design with the largest fillet radii that are practical for your project. **Outside corners should have minimum radii of .030".**

When holes, either through or blind, are incorporated into your design, keep the following guidelines in mind:

Through Hole Dimensions

Hole Size	Maximum Length
.04" to .08"	2 times the hole diameter
.081" to .2"	3 times the hole diameter
.201" to .4"	4 times the hole diameter
> .4"	6 times the hole diameter

Blind Hole Dimensions

Hole Size	Maximum Depth	Minimum Blending Corner Radii
.04" to .12"	.5 times the hole diameter	.5 times the hole diameter
.121" to .4"	1 times the hole diameter	.06" to .09"
> .4"	***2 times the hole diameter***	***.09" to .18"***

5. Comparison with Other Casting Methods

All metal casting processes have their own sets of benefits and drawbacks. The most appropriate process should be determined by a number of factors, including:

- Tooling costs
- Labor costs
- Design characteristics
- Desired appearance

In manufacturing, the most important factors are often tooling and labor costs, and the goal of the manufacturer and the supplier should be to find the optimal balance that produces the lowest per-part cost at a given quantity.

Here, we evaluate investment casting in reference to three metal casting processes: **shell mold casting**, **greensand casting** and **permanent mold casting**.

Shell mold casting: an Eagle Alloy operator vents a shell mold

Shell Mold Casting

Investment casting is known for its ability to hold to tight tolerances and produce parts with intricate inner cavities and excellent surface finishes. Shell mold casting, which involves heat-bonded sand patterns and cores, also offers comparatively high quality in the same categories. However, investment casting is able to meet much tighter tolerances than shell mold casting, and can offer even smoother surface finish.

Tooling costs for investment casting are generally lower than for shell mold casting, but the process requires highly skilled and sometimes tedious labor. As production volumes increase, per-part costs for investment cast products often overtake those of shell mold casting.

Both processes can accommodate nearly any alloy, including ferrous and non ferrous metals.

Greensand Casting

Greensand casting is another sand-based casting method, but this time no heat is applied. Instead, clay-like substances in the sand bind the particles together around patterns to create molds. In terms of tolerances and surface finish, greensand casting falls behind both shell molding and investment casting.

Greensand casting: an Eagle Aluminum operator pours molten aluminum into a greensand mold

When it comes to cost, however, greensand is often the winner. Tooling costs for greensand are lower than for investment casting, and the greensand process is not as labor intensive, resulting in fewer man-hours per part. Still, since greensand casting is a destructive mold process, per-pound costs quickly escalate as quantities increase.

Like investment casting and shell mold casting, greensand casting can also accommodate a wide variety of alloys.

Permanent Mold Casting

Permanent mold casting is the only non-destructive casting method on this list. Unlike investment casting, shell molding or greensand casting, molds in permanent mold casting are reused again and again. Instead of using sand or refractory material to build up mold walls, permanent molds are generally made of steel or cast iron.

Tolerances and surface finish for permanent mold casting lie somewhere between shell molding and greensand casting. None of these methods approach the dimensional accuracy and surface finish produced by investment casting.

For high volume runs, permanent mold casting is often the most economically viable option, but for low or medium volume runs, tooling costs are often prohibitive. Despite high initial tooling costs, labor costs for permanent mold casting are lower than other casting methods.

Since permanent molds, themselves, are made from metals, their melting points create limitations. Metals cast in permanent molds must have significantly lower melting points than the metals making up the mold. Therefore, permanent mold casting is often employed using aluminum or other non-ferrous alloys.

Permanent mold casting: an Eagle Aluminum operator pours molten aluminum into a permanent mold

Table 4: Comparison of Metal Casting Methods

	Tooling Costs	Labor Costs	Typical Tolerances	Surface Finish	Typical Volume
Investment	Medium	High	+/- .005”	Very Good	Low-Medium
Shell Mold	Medium	Medium	+/- .020”	Good	Medium
Greensand	Low	Medium	+/- .030”	Fair	Low-Medium
Permanent Mold	High	Low	+/- .010”	Good	Medium-High

An Eagle Precision operator prepares alloy for casting

6. Investment Casting Case Study

The purpose of this case study is to illustrate a typical process working with an investment casting foundry to bring a product to market. In this case, the customer already had a product that they were manufacturing through fabrication. The investment casting foundry was able to replicate the product, but improve upon it structurally and aesthetically while lowering per-part costs.

What is fabrication to casting conversion (or fab-casting)?

Fab-casting is a process change in manufacturing. It occurs when a manufacturer decides to replace fabrication with casting for the production of a part. Fab-casting is a common practice, and often provides a host of benefits for the part manufacturer, from cost savings to improved aesthetics.

Finding the Casting Candidate

While touring a client's facility, representatives of Eagle Precision Cast Products noticed a cable clamp assembly–a relatively complex fabricated part that they believed would be an excellent candidate for fabrication to casting conversion.

The fabricated part: underwater cable clamp, before redesign

The Product: Underwater Cable Clamp

The cable clamp that Eagle reps noticed was a hard working part. It was responsible for holding underwater communication cables in place for offshore oil rigs.

Eagle Precision prepared a proposal, outlining the process of designing, producing and assembling castings to take the place of the fabricated cable clamp. In their proposal, Eagle predicted that their process (investment casting) would prove advantageous over the old process (fabrication) in several ways. In this case, the benefits of casting vs. fabrication included the following:

- **Reduction of costs:** Investment castings are more cost effective than fabrication
- **Reduction of client manpower:** Eagle Precision's process delivers a finished product, whereas previous methods require the client to finish in house.
- **Reduction of machining requirements:** Investment casting is able to produce parts that meet tight tolerances, often reducing or eliminating the need for machining.
- **Reduction of part weight:** Cast parts can be efficiently designed to eliminate

excess material, reducing overall part weight.

- **Reduction of lead times:** Investment casting's dependable, repeatable process allows for shorter, more dependable lead times throughout production.
- **Improvement of part consistency:** Fewer variables in the casting process lead to enhanced part consistency, as do quality-control measures employed by Eagle Precision.
- **Enhancement of part strength:** Precise design and elimination of weld points contribute to an overall stronger part.
- **Enhancement of part aesthetics:** Investment casting allows for curved edges, smooth finish and unique, one-piece designs that can proudly display company names.

First steps: beginning the fabrication-to-casting process

Before beginning production, the client needed to make sure they would be getting a cast product that worked just as well as, or better than, the fabricated version. For the design stage, Eagle Precision offered casting and machining drawings on an hourly contract basis. Engineers at both companies worked together to produce drawings for the production of investment castings and finish machining of the cable clamp assembly.

After initial drawings were delivered, the two companies collaborated to optimize tolerances, minimize machining and maximize cost effectiveness while maintaining the integrity of the part.

Production of Cast Parts

Once all parties came to an agreement on the designs, Eagle Precision began the process of ordering tools and machining fixtures. They provided a lump-sum estimate that included the costs of delivering four tools (one for each component of the part to be cast) and machining fixtures, and estimated a lead time of 10 weeks for their delivery.

The two companies also worked together to determine the optimal material to use in the casting, which was **Alloy 316 stainless steel**. All components of the assembly, including accessories, would be cast using this alloy.

At this point, Eagle Precision was comfortably able to provide a per-part cost projection, based on a minimum of 200 assemblies in a batch. The client could clearly see that, as promised, the conversion to casting would save a significant amount of money.

After the client's go-ahead, Eagle Precision ordered the tools and cast the parts. The intricacy of the cable clamp assembly required that four castings be made and later assembled into a finished part.

Finishing the Castings: CNC Machining and Assembly

Eagle Precision worked with their sister company, Eagle CNC Technologies, to ensure quality machining on all parts. They ordered machining on all critical areas of the assembly where tolerances could not be held by the casting process itself.

Eagle Precision also assembled the cable clamps in-house, in order to deliver a product ready for sale.

Fab-Casting Results: Better Parts at a Lower Cost

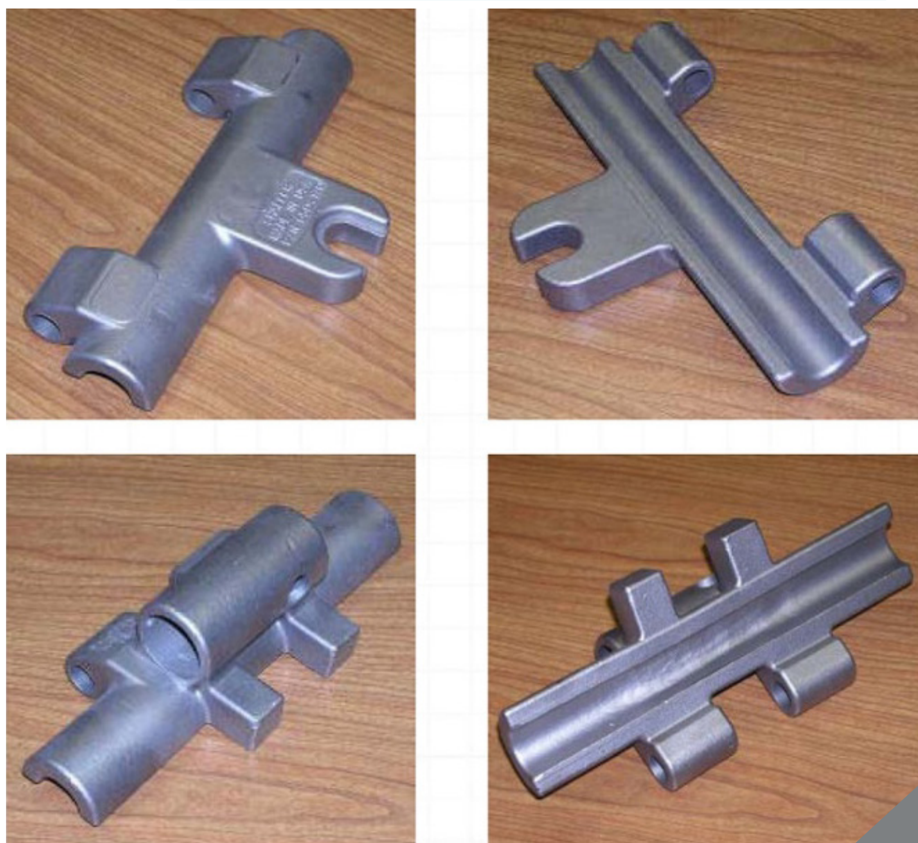
In this case, Eagle Precision's original predictions about the advantages of casting proved true. In fact, they were able to complete the first production run well within the original outlined schedule. Most importantly, they were able to produce a less expensive, stronger and more aesthetically pleasing part with faster, more consistent lead times.

Initial demand led to casting 5,000 - 6,000 parts per year, and the casting conversion saved the client over $100 per part, resulting in higher profit margins. Aesthetic and structural improvements to the parts also increased their resale value. Eagle Precision continues to produce this part today, though ownership of the client company has changed hands.

Another problem is that, often times, only a few employees have easy access to internal production costs. Buyers are often the ones interfacing with suppliers, but they might have to go to three or four departments to gather the data they need to make an accurate cost comparison.

Whether fab-casting is right for you will depend on a number of factors. It's always worth the time to contact a casting company to ask if your parts are good candidates for the transition. Who knows? Maybe your part could be the next "Cable Clamp Assembly."

The cast part: inside and outside views of the two cast pieces making up the redesigned underwater cable clamp



Is Fabrication to Casting Right for You?

The outcome of this case study is far from unique. At The Eagle Group, one of the main sources of casting business comes from converting fabricated parts. **But for every part that makes the switch, there are hundreds of missed opportunities.**

According to Deb Pipoly, Vice President of Eagle Precision Cast Parts, the biggest challenge is the knowledge gap. Many part manufacturers simply don't know about the benefits of casting, or they think that fabrication is more cost effective.

7. Glossary of Terms

Blind Hole - A hole that is machined or cast into a workpiece without breaking through to the other side.

Die - A metal mold used in the process of die casting, or used to make wax patterns in investment casting.

Gate - The area of the runner system where molten metal (or other casting material) actually enters the mold cavity.

Gravity pouring - The simplest method of filling a mold, using gravity to pull the molten metal down the runner and into the mold cavities.

Greensand casting - A common casting process, using moist, clay-bonded molding sand (Greensand) to form a mold.

Investment - Any process in which an object is dipped into liquid, and a layer of the liquid attaches itself to the object.

Lost wax casting - Now more commonly known as investment casting; an ancient casting technique that involves forming a pattern out of wax and coating it with refractory material to form a mold. Originally, the porous refractory material would absorb the wax when heated, resulting in apparently "lost" wax.

Near net shape - A classification of products, often castings, that require little or no finishing before they are put into use.

Pattern - An approximate replica of the part to be cast, used to shape the mold.

Permanent mold casting - A casting process employing reusable molds, as opposed to molds constructed of sand or refractory materials.

Runner - A channels through which molten metal is poured in order to reach the mold cavity.

Shell mold casting - A casting process that uses a thin layer of resin-bonded sand to form a mold.

Sprue - The main channel, also known as a downsprue, through which molten metal flows before entering the mold cavity.

Through Hole - A hole that is machined or cast into a workpiece so that both ends of the hole are open.

Tree - A cluster of wax or plastic patterns mounted together during the investment casting process.

Vacuum pouring - Also known as counter-gravity filling; a pouring technique used in metal casting that involves creating a vacuum to draw metal more quickly and completely into the mold.

Vacuum pressure casting - A pouring technique used in metal casting that involves the creation of a vacuum along with pressurized gas. The high-pressure area is positioned above the mold, and the vacuum below, creating a larger difference in pressure than a simple vacuum.

Endnotes

1 Hunt, L. B. (1980). The long history of lost wax casting: Over five thousand years of art and craftsmanship. Marshalltown, South Africa: International Gold Corporation Limited.

2 Webdental.com. (2018). Casting Procedures. [online] Available at: http://www.webdental.com/profiles/blogs/casting-procedures [Accessed 28 Mar. 2018].

3 Degarmo, E. Paul; Black, J T.; Kohser, Ronald A. (2003), Materials and Processes in Manufacturing (9th ed.), Wiley, ISBN 0-471-65653-4.

4 AFSInc.org. (2018). Investment Casting FAQs | AFS. [online] Available at: http://www.afsinc.org/content.cfm?ItemNumber=6904 [Accessed 29 Mar. 2018].

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About Eagle Precision Cast Parts, Inc.

Eagle Precision is an investment casting foundry pouring both ferrous and non-ferrous castings.

Eagle Precision is one of three independent companies that make up [the Eagle Group]. Together, the Eagle Group provides full-service metal casting and CNC machining services utilizing a wide variety of state-of-the-art tools and techniques.

Eagle Precision Cast Parts, Inc. was founded in 1991 by Mark Fazakerley and John Workman to complement their already successful shell mold sand foundry, Eagle Alloy, Inc. Eagle Precision first sold an investment casting to a military antenna manufacturer that had production requirements of up to 2500 pieces per week. With Eagle Precision's consistency and high level of quality and attention to detail, the company continues to supply this casting to the same customer for the same military application.

Eagle Precision has grown steadily since its inception, and now produces over 1000 different part numbers across many different industries. Eagle Precision is located on the same Muskegon, MI campus as Eagle Alloy, Inc., and continues to expand its facilities as demand grows.

Eagle Precision Cast Parts takes pride in the company's reputation for producing top-quality parts that regularly exceed expectations.

To learn more, visit us on the web at

www.eagleprecisioncastparts.com

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