By using the built in advantages of steel alloys and the design flexibility and close dimensional tolerances of investment casting, designers are able to produce high-strength castings at a cost-effective price.

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Investment casting represents one key thing to casting designers—possibility.

The investment casting process gives casting designers a great deal of liberty in their designs, allowing them to play up material properties (including complex geometry that allows for simultaneous thin and thick walled sections) that are key in the design of their component. Nowhere is this more evident then when the process is combined with steel alloys.

In investment casting, wax or plastic patterns are coated in ceramic slurry to produce a mold. After melting out the pattern, the empty mold is preheated and then ready for pouring. While most investment castings typically way less than five lb, the process can be used to cast much larger castings.

This article takes a look at what can be obtained with steel investment casting, and provides several examples of castings that have gotten the most out of the process.

Design Possibilities

There are several areas where steel investment castings can aid a casting designer looking for the best combination of material and process. These advantages can include thin walled castings, excellent surface finish and an easy castability of complex casting geometry.

Thin Walls—When most people think of the material properties available when casting with steel, the first thought that comes to mind is rarely thin walls. However, through investment casting, steel castings are branching out into new markets such as automotive, aerospace and truck manufacturing by creating lightweight, high strength, thin-walled castings.

While nearly all steel castings offer superior strength, ductility and fatigue life over other metals, casting thin sections has been a challenge. The current comfort level has traditionally been 6 mm using a traditional sand molding process. However, by combining steel with the investment casting process, steel castings have been produced with walls of less then 2 mm.

Surface Finish—Investment cast parts are cast to “near-net shape,” reducing metal and machining costs. When coupled with a stainless steel alloy, surface finishes of up to 135 RMS can be obtained. “You can eliminate a lot of polishing for castings that will be exposed,” said Kristine Coyle, president of Independent Steel Casting Co., New Buffalo, Michigan.

“Stainless steels are traditionally popular in the food preparation industry as they are not corrosive,” Coyle continued. “It is important that they avoid rust so that rust particles do not break off and go into food items.”

Complex Geometry—Investment casting can produce compound, three-dimensional curved surfaces, and also can incorporate strengthening design values, including corner fillets and streamline transitions that can avoid weak notches created by machining. Also, by eliminating machining all together, the process saves on value-added costs.

While use of investment cast steel can help in lots of areas, there is one specific area where it can be something of a hindrance. Investment casting generally requires large production runs due to the
high initial cost of dies for the wax patterns. While they are cost effective in the long run, a separate wax and shell must be made for every cast produced. This makes the project not conducive for small volume work.

In general, investment casting is targeted to higher production parts due to the high cost of tooling for wax patterns. However, the process has gained real life in the last 10 years for prototype parts and short runs as many rapid prototyping systems are now able to produce wax-like patterns of single parts from CAD data. The patterns can be invested into a mold and then follow the traditional investment casting process. As a result, prototype investment castings are produced without tooling.

Understanding Steel Alloys

Steel is a very flexible metal. When looking at the optimal steel alloys for your component, it’s important to understand what material properties the alloys can bring to the table, and how the investment casting process can best accentuate them.

**Carbon and Low-Alloy Steels**—When using carbon and low-alloy steels in the investment casting process, a wide variation of mechanical properties can be achieved, either by choice of composition or heat treatment. These alloys are generally used for their superior combinations of proof stress, ductility, toughness and hardness (tensile strength up to 250 ksi, elongation values up to 30-40%, low temperature impact values up to 30 ft/lb at -50-100°F), which enables uniform properties to be achieved throughout castings.

Most low alloy steels contain manganese (Mn), chromium (Cr), nickel (Ni) and molybdenum (Mo) as the principal alloying elements. These can greatly influence the material properties possible. Steel alloys that contain 1.5% Mn pearlitic manganese allow for superior properties in plain carbon steels, while various Cr-Mo and Ni-Cr-Mo steels can achieve excellent shock, fatigue and wear resistance through a combination of alloy composition and heat treatments. Low alloy material with yield strength in the range of 200-250 ksi will have fracture toughness values between 50-100 ksi-in$^1$.

For castings that require a high level of wear resistance, there are several surface hardening techniques such as carburizing, cyanide treatment or nitriding. This enables the castings to have a high abrasion resistance (hardness values well above 60 HRc), which is particularly effective when combined with a strong core.

**High-Alloy Steels**—Most high-alloy steels are required to have a high resistance to corrosion, high temperature, wear or combinations of these conditions under varied circumstances of stress. Such alloying elements as Cr and Ni contribute to the special characteristics of the alloys due to their inherent good casting properties. However, there is a significant cost difference between low and high alloy steels.

While low alloy steels can range from $0.15-0.25$ per lb, high alloy stainless steel range from $1.00-$3.00 per lb.

There are two main types of conventional stainless steels:

1. Ferritic-Martensitic Steels—These alloys contain a basic 13% Cr composition, which increases the level of corrosion resistance due to the attainment of a continuous protective Cr-rich surface oxide film. With increasing carbon content, the ferrite structure becomes hardenable by oil quenching and tempering, offering varied tensile properties and hardness with changes in carbon content and heat treatment. Higher strength and hardenability (tensile strength up to 300 ksi, with a max hardness of 60-62 HRc) can be obtained by increasing the chromium content to 18% and introducing varied amounts of carbon. There is no Ni in martensitic or ferritic stainless steel.

2. Austenitic Steels—Austenitic stainless steels contain a minimum of 18% Cr and 8% Ni and offer superior corrosion resistance compared to ferritic and martensitic stainless steel, but are no longer hardenable through heat treatment, due to the balance between Cr and Ni and other elements.

Exceptional combinations of properties (such as transverse strength, ductility, and toughness) can be achieved in investment castings using high alloy steels, which undergo secondary hardening. Several examples of these properties can be seen in Table 1. The strength and ductility of these materials, combined with good corrosion resistance and suitability for high temperature use, provides a highly versatile class of investment alloys.

**Casting for Investment Casting**

Tech Cast, Inc., Meyerstown, Pennsylvania, was recently commissioned to redesign an investment cast steel component to be used in investment casting operations. The component, the tree coupler (Fig. 1), is used for rapid attachment of the wax tree assembly to the shell building robot handle.

"The part was originally a plain thread-

![Fig. 3. This mounting bracket for a medical centrifuge was converted from a weldment at a cost savings of more than 450%.](image-url)
ed rod and seven-piece hardware assembly,” said Shawn McKinney, chief metallurgist at Tech Cast. “By redesigning the component we were able to reduce the amount of hardware from seven parts to three, and reduce the number of joints that required tightening from three to one.”

While designed as an investment casting, McKinney says that it would have been possible, but not as profitable, to produce the component in another method. “It could have been produced as a forging, but that would have required secondary finishing operations, as well as high tooling costs. Bar stock was also considered cost prohibitive due to the extensive machining operation required to achieve all necessary design features.” The investment cast coupler required no secondary machining operations. The coupler was cast with an IC 4140.
low alloy steel, which was chosen for its strong mechanical properties and castability. The component also was heat-treated to a hardness value of HRc 30-35. “The coupling system has dramatically reduced the overall time to attach the wax trees to robot pickup handles by an average of 53%,” McKinney said. “It can save an average of $2235 monthly in labor.”

Military Applications

Investment cast steel castings also are found in several military operations, such as the housing for a directional thrust reverser that goes into the fitting for a KC 135 military aircraft (Fig. 2). The casting, which is produced by Independent Steel Castings Co., was investment cast due to its complicated configuration, which includes a high contrast in section thickness and high casting quality requirements.

“To achieve the configuration necessary for the component, we used soluble wax cores to create the internal contours and heat treated the parts to meet the 150-170 ksi strength requirements,” said Coyle.

According to Coyle, while the component could have been cast with another alloy, steel was the most effective choice. “A die cast part made out of aluminum can be produced out of stainless steel 302 with greater strength, improved corrosion resistance and lower tooling costs,” said Coyle.

Medical Centrifuge

In order to cast a mounting bracket (Fig. 3) for a medical centrifuge that turns at more than 1000 RPM, Vestshell, Inc., Montreal, Quebec, Canada, had to convert an existing weldment into a stronger precision component while simultaneously reducing costs.

The foundry was able to reduce the costs by converting the component to a casting by more than 450%. They also were able to provide dimensional repeatability through the investment cast process and maximize the castings high-strength qualities through the CF3M stainless steel alloy. The customers also saw an improvement in surface finish thanks to the use of stainless steel.

By using investment cast steel, the foundry also was able to realize more consistent component quality. As of the initial production, the customer had seen nearly 800 parts without encountering casting-related defects.