When converting existing iron components to aluminum, designers must analyze each alloy's properties to ensure the best fit for their component.

Joseph Maffia, Assistant Editor

Most designers who look to aluminum as a possible conversion material from an existing iron component are looking for one thing and one thing only—mass reduction. This desire can be so passionate that designers can overlook other factors in the alloy/geometry interface in the early design phase, causing problems down the line.

While converting an existing iron component to aluminum can offer several advantages, there also are several pitfalls that can trap a designer who may not understand the fundamental differences between the two alloy families. Designers should become familiar with those differences before deciding if iron or aluminum is best for their component.

The trend toward lightweight aluminum components continues to grow, and can be seen most clearly in the automotive industry, where aluminum has replaced significant percentages of cast iron components. According to Stratecets, Inc., by 2004, cast aluminum's estimated penetration into motor vehicles (by percentage of total produced) includes 45% of engine blocks, 90% of cylinder heads, 30% of suspension parts, 30% of differential carriers, 33% of intake manifolds, 75% of wheels and 98% of transmission cases. While Stratecets only forecasts a 2.6% increase in motor vehicle production in 2003, continued conversions from iron in motor vehicle applications is expected to spur a nearly 10% growth in aluminum casting shipments.

Following a trend is not a sufficient reason for a designer to change an existing iron casting to aluminum. So, what should designers consider when...
Casting Case: Steering Knuckle

Internet Corp. took a steering knuckle (Fig. 2) that was traditionally cast in iron and converted it to aluminum using its proprietary pressure counter pressure casting process (PCPC), a variant of low pressure casting technology. The PCPC process uses counter pressures in the furnace and casting chamber to control mold filling and maximize feeding in shrinkage-prone regions of the casting along with sequenced cooling of the mold to ensure directional solidification.

“We wanted to reduce the weight while maintaining performance requirements, including fatigue strength, impact resistance, improved machinability and lighter weight,” Prucha said. In order to keep a constant level of fatigue strength, the wall thickness had to be increased in several areas. Ribbing was also added for additional strength. The aluminum casting provides a 40% weight reduction over the traditional iron version.

Fig. 2. This steering knuckle cast by Internet Corp. was traditionally cast in iron. In order to maintain required levels of fatigue strength, the wall thickness was increased in several areas, resulting in a weight reduction of 40%.

contemplating this change?

This article looks at the advantages of aluminum conversion and the possible problems that designers can incur in the process. By being aware of these problems, designers can consider which characteristics of the alloy and geometry interface are most important for their component, and whether iron or aluminum is the better cast metal to achieve the overall design objective.

Casting Case: Engine Cooler

Boose Aluminum Foundry Co., converted (and consolidated) a pressure plate engine cooler (Fig. 3) for large engines from three existing iron components to one aluminum casting. The component was reduced from 180 to 61 lb, a weight savings of 66%. The pressure plate was designed to integrate the expansion tank, crossover piping and a refrigerant degradation feature in addition to its original cooling application. The consolidated design also provided the customer with a nearly 40% cost savings on the component due to the reduced assembly design.

Fig. 3. This pressure plate engine cooler for large engines from Boose Aluminum Foundry Co. was redesigned from three iron components into one aluminum casting, reducing the component’s weight from 180 to 61 lb.

Contemplating Aluminum

Mass Reduction—Nearly every conversion to aluminum is performed with the purpose of reducing component weight, as aluminum is approximately one-third the weight of iron. However, mass reduction and cost are related in a complex way. Molten aluminum in its base form is three to four times more expensive than molten iron. Further, the strength and stiffness achievable with iron forces aluminum castings to have more thickness and/or more geometry to compensate. Consequently, aluminum casting designs converted from iron save about half of the weight of the original iron component, rather than the two-thirds weight savings that the density difference would imply.

Value comparisons between the two metals are best made in terms of the total downstream component cost in actual use. One example is fuel savings from a lighter, but more expensive aluminum casting, which would make a component less expensive in actual use.

“Even though gray and ductile iron are cost effective materials, switching to aluminum can achieve rolled-up cost savings through lower melting energy consumption and lower molding energy and labor consumption,” said Michael Gwyn, director of metals technology at the Advanced Technology Institute.

Mass reduction can lead to transportation freight cost savings for both the foundry and the customer. “Aluminum is replacing iron in exercise equipment, because the unit is cheaper to ship,” Gwyn said. “The lower weight also makes the equipment easier for the consumer to set up.”

Cost savings also can occur in castings that require heavy machining. Because aluminum is a softer metal than iron, excess machine stock is machined off faster, im-
proving machining productivity (see sidebar, “Conversion Case Study: Littlestown Foundry, Inc.” on p.33).

**Thermoconductivity/EMI**—Another advantage to aluminum is its high level of thermoconductivity. “Aluminum is often found in electrical enclosures because it dissipates heat better than iron and provides excellent EMI shielding,” said Tom Prucha, vice-president—technical services at Intermet Corp. “Because of this, aluminum is replacing iron components in radios and other electrical components.”

**Reduction of Inertia Forces**—A direct consequence of aluminum’s lower mass is reduced inertial forces in machinery that has components that start and stop rapidly. “When a machine changes directions quickly, the inertial forces can become large,” Gwyn said. “Therefore, the moving tooling heads on multi-axis CNC machine tools are increasing using aluminum components rather than iron.”

**Possible Design Pitfalls**

While aluminum offers many advantages, several key distinctions exist between the two materials that must be kept in mind during casting design.

**Thickness Levels**—Weight savings hoped for in conversions from iron to aluminum is blunted by the lower strength and stiffness levels of aluminum. “Aluminum has approximately 75% of the strength of ferrous metals,” Prucha said. “If the same level of tensile strength and ultimate yield strength is desired in the new aluminum component that was present in the previous iron component, this must be rectified with increased section thickness or a design change to better distribute the load.”

Prucha warns however, that by increasing the section thickness, a percentage of the weight reduction is lost. “Instead of having a part that has a 65% weight reduction, after you increase wall thickness you now have a part with only a 40-45% weight reduction,” Prucha said.

Increasing the section thickness of a component may lead to other design problems. One possibility is that when the part becomes physically bigger, it may not fit the packaging space in the end product. “Designers also must consider the outside edges and any attachments such as bolts or connectors,” Prucha said. “If a round peg is made larger when converted to aluminum, it is still going to have to fit in the same hole.”

“Occasionally in tight automotive and aircraft structures, this size constraint can overrule an aluminum casting conversion,” Gwyn said.

**Stiffness**—The stiffness level of aluminum also is much lower than that of iron. The modulus of elasticity in tension for ductile iron is 24 x 10^6 lb/sq in. and for gray iron is 13 x 10^6 lb/sq in. For aluminum, it is 10 x 10^6 lb/sq in. This is a dramatic drop-off from the initial iron component.

“The new aluminum component must compensate for the loss in stiffness,” Gwyn said. “The best way to do that is by using stiffness from geometry, which is called area moment of inertia. In critical stress regions of the aluminum component design, area moment of inertia can augment the lost stiffness from the change in alloy.”

**Casting Inspection**—When designers maximize weight savings they must inspect the components more extensively for defects. “Because the parts have less mass, flaws or defects have a more pronounced effect,” Prucha said. This can lead to higher costs in

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**The Iron Equalizer: Austempered Ductile Iron**

Aluminum hasn’t cornered the market on low-weight conversions just yet. Austempered ductile iron (ADI) is ductile iron that undergoes a specially designed austempered heat treatment. Because the heat treatment is isothermal in nature, the volumetric growth during the process is predictable and repeatable. ADI offers engineers flexibility, low weight, excellent fatigue strength and wear resistance. ADI also comes at a lower cost than aluminum because of its castability, lower machining cost due to nearer net shape manufacturing, a lower heat treating cost and 100% recyclability.

As in all other conversion processes, designers should not substitute ADI without considering design modifications that must take place. In some cases, ADI may require larger fillet radii than cast or forged steels. Also, stiffness may need to be increased in some designs to compensate for the lower modulus of elasticity commonly found in ductile iron.

In one conversion example for ADI, Applied Process, Inc., converted a one-piece automotive wheel spindle/knuckle from aluminum to ADI (Fig. 4). The ADI component provided a 40% cost reduction over the aluminum knuckle with a pressed steel spindle.

The one-piece component also saw improvements in cost per unit of yield strength, improved fatigue strength, enhanced wear resistance and superior noise dampening characteristics in comparison to the original aluminum component.

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**Fig. 4. This one-piece automotive wheel spindle/knuckle from Applied Process, Inc., was converted from an aluminum knuckle with a pressed steel spindle into austempered ductile iron, providing a 40% cost reduction and improved fatigue life and wear resistance.**

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Aluminum alloys also can cause problems during casting. Gray and ductile iron alloys do not have problems feeding from heavy to thin wall thicknesses since they utilize progressive solidification. Aluminum, which follows directional solidification, may have shrinkage problems because of slower rates of solidification.

"When designing for aluminum, it is important that the design has the appropriate feeding channels so that hot spots can be avoided," Prucha said. While aluminum also may be prone to hot tearing, different alloys can be used to avoid such problems.

Temperature—Iron has a higher melting point then aluminum—approximately 2400°F (1315°C) for iron vs. 1100°F (593°C) for aluminum—allowing iron to maintain its material strengths at higher temperatures then aluminum.

"Once the temperature reaches higher then one-third of the melting point, the component begins to experience a loss of materials properties," Prucha said.

"For aluminum, this means that its strength begins to drop off dramatically around 300-400°F (149-204°C). Iron can withstand up to 1000°F (538°C)."

There are ways that aluminum can survive under increased temperature conditions. "Because aluminum has a higher level of thermal conductivity, it dissipates the heat well as long as the heat can be removed through airflow," Prucha said.

"This is why aluminum works in cylinder heads and engine blocks."

The Choice

While aluminum conversions from existing iron components can lead to several advantages—most paramount among them mass reduction—designers must be careful to ensure that they make the correct decision. Only after understanding the material differences between the two metals and carefully altering the original iron component design can a designer commit to a conversion to aluminum. According to Prucha, "You cannot just pull up your existing iron mold and pour in aluminum."