

LIGHTENING THINGS UP FOR DIESELS

Proper selection and use of aluminum alloys can provide weight savings, fuel economy benefits for engines, heavy-duty trucks



COMMON ALUMINUM ALLOYS	
Alloy	Comments
A319	Common for heads and blocks.
A354	Higher strength, moderate high-temperature strength; common for turbochargers.
C355	Slightly harder than 356; Copper content for elevated temperature properties.
A356	General use alloy; good performance, good value.
357	Higher yield strength than 356 with somewhat lower ductility.
A206	Suitable for structural applications; 2x the strength of A356 at 150°C.
242	Al-Cu alloy with nickel. Works well for air- and liquid-cooled cylinder heads.

Aluminum alloys typically used in engine design over the past few decades.

BY ANDREW HALONEN

There is an ever-increasing need for lightweighting in on-highway vehicles such as heavy-duty trucks. As of this year, new commercial trucks must meet greenhouse gas (GHG) emissions and fuel economy standards, and those standards will become even more stringent in 2018.

To meet diesel emissions requirements, truck manufacturers have added diesel particulate filters (DPFs) and selective catalytic reduction (SCR) systems, which in aggregate add hundreds of pounds to the vehicle's weight. To meet regulations to reduce stopping distances, manufacturers have had to increase the size of the brake drums, which also brings a weight penalty. Improved aerodynamics, driven in part by the fuel economy and GHG standards,

Andrew Halonen is a sales engineer for Eck Industries Inc., an aluminum casting specialist based in Manitowoc, Wis.

have added to vehicle efficiency, yet those components can often weigh hundreds of pounds.

Idle-reduction programs have spurred the adoption of auxiliary power units (APUs), but both battery-

based and diesel-powered units can add up to 500 lb. to truck weight. Conversions to natural gas can deliver a return on investment in as little as two years, yet the package can add 2000 lb. to the truck.



An iron cylinder sleeve that has been cast within an aluminum head.

Finally, to attract and retain drivers — a significant concern for fleets — premium interior packages can add 100 lb. or more. Add it all up and the premium “fuel-efficient” truck can weigh 2390 lb. more than the standard truck.

Thus, there are many opportunities for lightweighting, many of which are based on replacing steel and other materials. Forged aluminum wheels can be used in place of steel wheels. Iron hubs can be replaced with cast aluminum. Other options include a forged-aluminum fifth wheel and sheet-molded composite body panels, along with a 6x2 axle arrangement. The 6x2 setup, using one fewer drive axle, can save 400 lb.

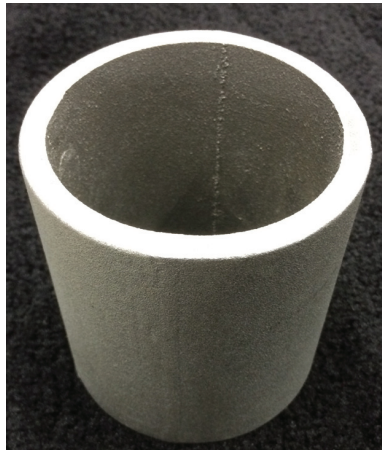
There are also considerable opportunities to reduce the weight of the engine as well, using recent developments in metals and processing.

Diesel engine manufacturers have been using aluminum for a long time, yet the material is not as common as it is with gasoline engines. DeltaHawk, a manufacturer of diesel aviation engines, has been producing engines with cast aluminum blocks and heads for more than a decade. Mercedes-Benz began using cast aluminum blocks in diesels in 2005, and the engines used in 2014 Sprinter vans have cast aluminum heads and a block with a compact graphite iron cylinder sleeve.

More recently, the new 5 L Cummins ISV5.0 diesel incorporates an aluminum intake manifold, aluminum pistons and a high-strength aluminum alloy cylinder head (see March 2014 *Diesel Progress*).

Compared to standard cast iron materials, aluminum has a lower density — 0.1 lb./cu.in. in comparison to 0.26 lb./cu.in. for gray iron. It is corrosion resistant, it rejects heat at three times the rate of iron and is relatively easy to machine and recycle. From a manufacturing perspective, it can also be easier to cast complex cooling water jackets in aluminum.

Drawbacks of aluminum are a reduction in stiffness, wear resistance



A cylinder liner made from an aluminum-silicon carbide (Al-SiC) graphite composite, also known as metal matrix composites.

and vibration damping, and it is less tolerant of elevated temperatures than cast iron.

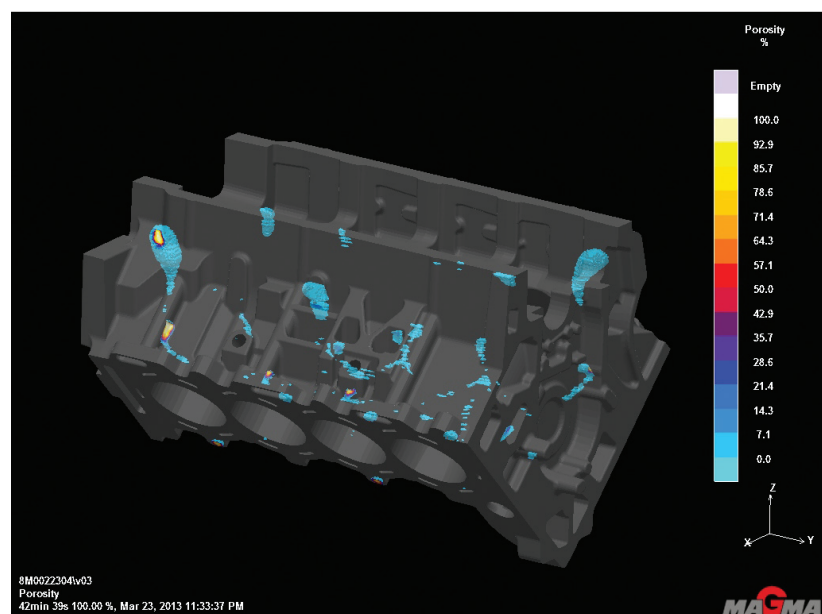
However, the high-temperature performance capabilities of aluminum have been improved with the addition of scandium, as explained in the American Foundry Society paper, “Development of Cast Al Alloys for Elevated Temperature (250°C) Service,” by D.J. Weiss, G.A. Gegel and K.S. Sadayappan. Aluminum-scandium alloys demonstrate mechan-

ical properties at 250°C (482°F) that are 3.6 times higher than wrought aluminum alloy 2618 and 2.1 times higher than cast 354 aluminum.

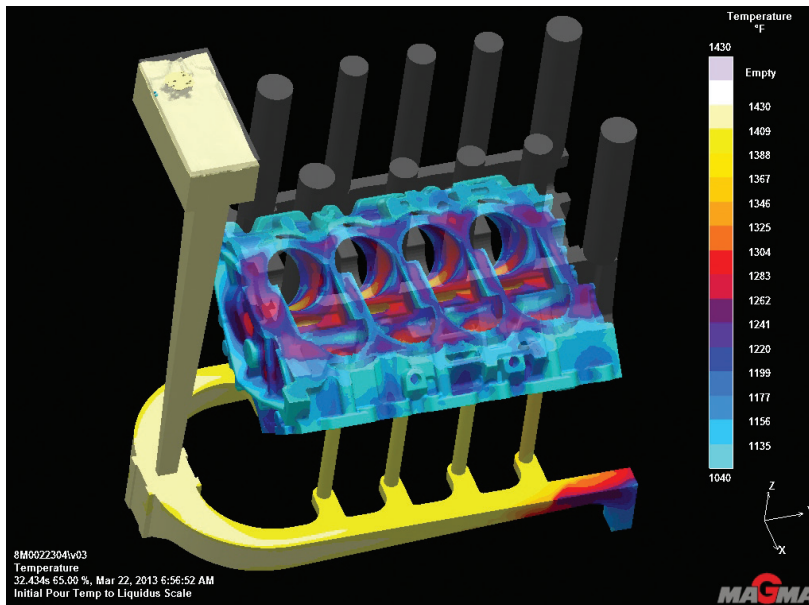
Variations of metal alloys show promising results. By reducing the silicon content of A356 aluminum from the normal 7 to 4%, the strength remains the same yet the elongation improves by 75 to 100%. This bodes well for longer-lasting intake manifolds and cylinder heads.

The 200 Series aluminum alloys use the addition of copper and other elements to improve performance — 206 has some titanium; 201 has silver; 224 has titanium, zirconium and vanadium; 242 has titanium, nickel and chromium. These alloys improve performance at elevated temperatures when compared to the common Al-Si alloys, and A206 shows a dramatic improvement in low cycle fatigue, which is a critical design parameter in engine design.

While it is common to have steel or iron liners in the block, Eck Industries has been developing aluminum composite liners made with silicon carbide and graphite within an aluminum matrix. The silicon carbide provides stiffness and wear



Natural solidification simulation can be used to show problematic areas of a casting at the design stage.



Flow simulations can show how certain metals behave when being cast.

resistance and the graphite provides lubricity to minimize the amount of oil and concerns of oil blow-by. Testing on cast aluminum compressors with iron sleeves versus the compressors with composite sleeves shows a 60° to 80°F reduction in cylinder temperature due to the improved conductivity of an aluminum composite sleeve over an iron sleeve. The weight reduction is similar to that of iron converted to aluminum.

Aluminum-silicon carbide composites, commonly known as metal matrix composites (MMC), have also been considered for the main bearing caps on aluminum blocks. MMCs are 20 to 50% stiffer than aluminum and have a lower coefficient of thermal expansion.

There have also been considerable advancements in aluminum casting technology that will further enable lightweight engine design. The modeling and simulation technologies for engine development are improving daily. 3-D printing helps engineers visualize and communicate new designs and provide a means to significantly reduce the time to produce working prototypes. In the foundry, simulation tools used to represent metal flow have improved

considerably, as well. Analysts can accurately predict areas of porosity, high velocity fill, temperature, and the mechanical properties in some alloys. Working with a conceptual design CAD model, a natural simulation model can show areas of concern relative to porosity.

Once the tool build begins, casting engineers work with design engineers to understand the areas that need the highest material properties and areas that can be aligned with

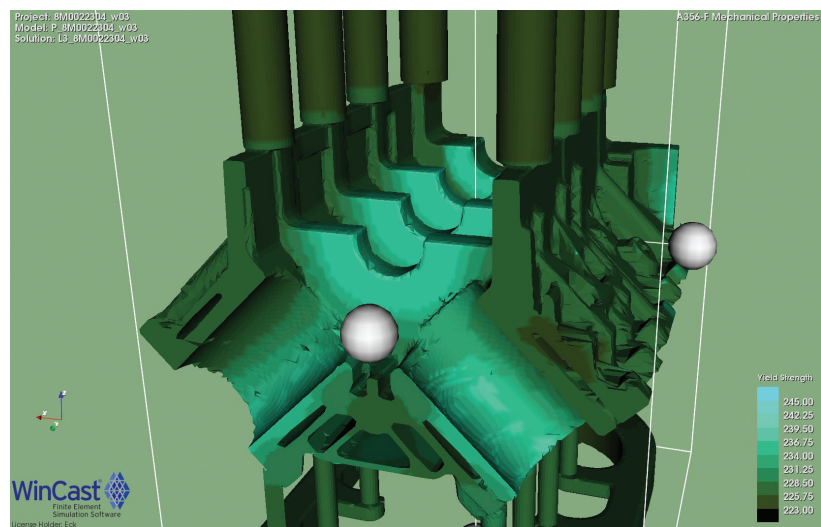
the material feed gates and backfill risers. When this collaboration begins in the simulation stage, the result is a higher performance casting and a more repeatable, reliable manufacturing process.

The manufacturers of metal flow simulation software tools collaborate with foundries to ensure that their models represent real-world results. Not all materials flow the same, especially considering the Al-Si alloys and the Al-Cu alloys. The latter, like A206, deliver considerable higher strength, fatigue, elevated temperature performance, yet with the lack of silicon, the flow and solidification are considerably different than the common cast A356 aluminum.

As the simulation tools improve, engineers can use them to predict properties within the casting.

Escalating demands for performance, fuel economy and emissions reduction will continue to push manufacturers to consider different alternatives to reduce weight in their products. Design engineers, working with their foundry partners, can work to develop lightweight engines that will keep the diesel engine at the forefront of the innovation curve. **dp**

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This finite element simulation shows the predicted properties of a cast aluminum engine block.