Performance Pistons & Rings

—Innovations In Materials & Manufacturing

Pistons and rings face the front lines of power, converting cylinder pressure into mechanical motion while sealing up the full fury of internal combustion. "The biggest challenge we face today is heat," noted Keith Jones of Total Seal, Phoenix, Arizona. "We're making more power with smaller displacements, using turbochargers and superchargers. Even four-cylinder production engines are making 300 horsepower. And we have more exotic fuels arriving all the time. We're seeing more oxygenated racing fuels, and fuels that force pistons and rings to operate in a drier environment." Lighter-weight materials and new cylinder-bore surfaces further complicate the equation.

These and other challenges are forcing manufacturers to re-think how pistons and rings are engineered. "Pistons have evolved over the last few years," observed John Levis of Wiseco Performance Products, Mentor, Ohio, "and most of the changes have been to improve durability, strength and weight."

The problems are significant, but solutions are arriving—and from surprising sources.

Significant Bores

Even the chemistry and composition of cylinder bores is changing—and diversifying. "Traditionally, we've always dealt with iron cylinders," said Jones. "And then Nikasil became more prevalent. And now Aulsil is coming back, and several new variants have appeared, all with higher silicon content. It's great stuff, but from our side it changes things. The engine manufacturers come to us and say, 'We need a ring to run on this.' And we say, 'Tell us about its characteristics.' And they say, 'We need a ring to run on this.'"

That puts the onus on the ring manufacturers to find materials and coatings that work with these new bore surfaces. "We start with the stable of coatings that we know work well," he continued. "We look at the characteristics of the bore material: how it holds oil—or doesn't hold oil. What is the working environment? And hopefully the engine manufacturer is willing to work with us and do some testing. We're working right now with a nine-cylinder

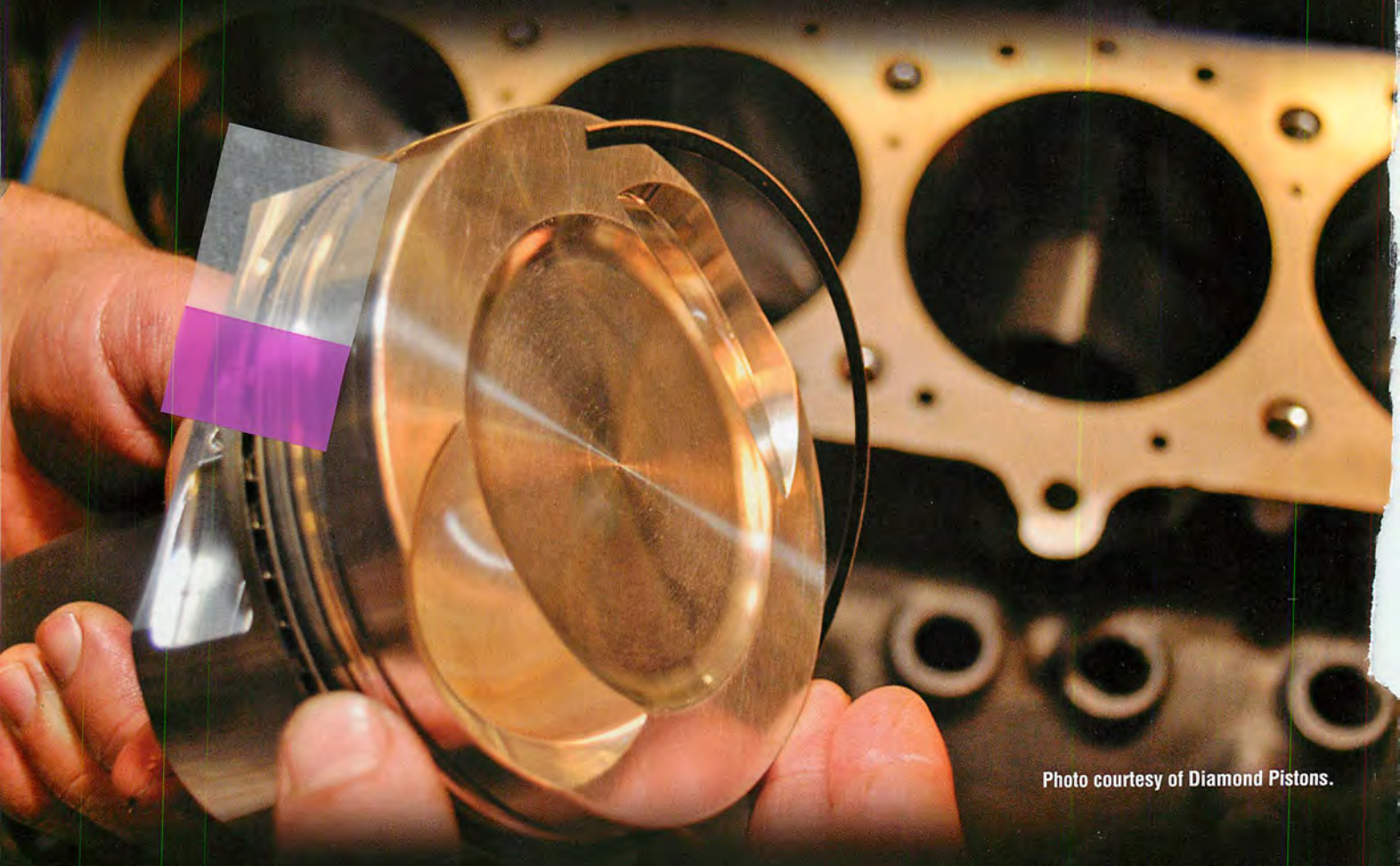

Photo courtesy of Diamond Pistons.

By John F. Katz

From custom creations to shelf stock selections, here's a review of the latest piston and ring designs available for this season.

radial engine, and we're testing five different coatings at the same time. We literally have something different in each hole. We're running 50-hour, 100-hour, 300-hour tests, steady-state and wide-open, and then we look at everything when it comes out. And we're not just running different ring coatings; all the cylinders have different bore coatings as well."

The twin-turbo radial engine is being developed to drive pumps or generators at remote locations, often running at very high output for hundreds of hours at a time. "It's not a racing engine," said Jones, "but it's very high-output, and has to be able to run on gasoline, methanol, natural gas and other fuels. So we can take what we've learned from it and apply it to the racing world."

The ability to run on multiple fuels is significant. "Major sanctioning bodies have mandated a change from gasoline to various blends of gasoline and ethanol," Jones noted. "NASCAR now mandates Sunoco Green E15, which is 15 percent ethanol by weight. The Australian Supercar Championship runs on E85. Those are much drier-running fuels than gasoline. Most racing gasolines contain lead, which is a lubricant, and when you switch to an ethanol blend you are removing that lubricant from the fuel. So now we see premature wear issues, not just in the rings and the cylinder bores, but also in the valves and valve guides. And at the same time the season for testing gets shorter"—making the ability to leverage experience in other industries more important than ever.

Particular Pistons

As with so many other racing components, demand for custom-made pistons is increasing. "For domestic engines," said Ric Panneton of CP-Carrillo, Irvine, California, production is "70–75 percent custom; while imports and powersports are 25–30 percent custom. Diesel is 100 percent custom at this time." Custom machining is driven largely by rapid innovation in cylinder heads. "We offer myriad custom features: valve pockets, dome designs, cam/barrel designs, even dynamic piston balancing. We use dedicated fixturing and machine sequencing for consistently tight tolerances. We can also manufacture pistons from billet, which allows rapid development of new designs, while keeping our piston technology current, without being chained to an existing forging that may impose limitations on a new project."

In addition to its custom work, CP-Carrillo offers an extensive line of forged pistons for domestic, import, and powersports applications; and recently released its CP-Bullet line, "packing all of our technology into a more affordable package," said Panneton. "We designed forgings that we could purchase in quantity and machine for many applications. Then our 'Smart Machining' process cuts manufacturing time without cutting quality. Our Bullet pistons are made to the same tight tolerances as our standard line, and they come with a premium ring set."

Myriad challenges have forced piston and ring manufacturers to rethink how their products are engineered. Most of the recent piston evolutions have been to improve durability, strength and weight. While the problems are significant, innovative solutions are arriving, and from a number of sources. Photo courtesy of Wiseco.

Chris Madsen of Ross Racing Pistons, El Segundo, California, estimated custom orders to be 65 percent of production, "which is down from a few years ago due to the expansion of our shelf-stock line." Madsen added, "Customs are our mainstay, and I don't see that changing anytime soon. The majority of our customers are professional or extremely serious amateur racers who rely on advanced machining processes that are just not economically feasible in a shelf-stock line." Ross has "changed the way we secure the forging during the machining process. This has produced a few benefits, the most important being improved machining accuracy, allowing us to hold tighter tolerances in critical areas such as ring grooves and skirt profiles. It has also improved production efficiency, thus shortening our delivery times." Madsen noted the growing popularity of direct fuel injection, requiring "more intricate bowl and dome configurations."

"Approximately 25–30 percent of Wiseco pistons are customs," added Levis, "and we see this trend growing as customers try to save their blocks by ordering slightly oversized pistons. Our goal is to analyze trends in custom pistons and turn them into shelf-stock items for faster service to our customers." As an example, he pointed to Wiseco's Quick 16 and Quick 8 big block Chevy pistons. "These are now our best-selling shelf-stock pistons for the domestic market." Wiseco's new GM LSX pistons have also proven extremely popular, he said.

Wiseco offers "shelf-stock parts for domestics and sport compacts," Levis continued, "from conventional forgings (full round or slipper skirts), or the newer, strutted/inboard brace design, depending on usage and horsepower requirements." Wiseco's custom line also includes full round, slipper, and strutted forgings, "plus billet, which allows us to build pistons for extreme high horsepower—2000 and up. Big-inch twin-turbo race engines, where maximum strength is a must, usually rely on custom billet designs. Making pistons from billet also allows us to mill under the crown for uniform dome thickness, providing lighter pistons for naturally aspirated engines. We also offer 3D dome milling, allowing engine builders to optimize weight versus combustion chamber design. This is particularly popular in sprint cars and in Super Stock drag racing."

In order to improve product offerings, piston and ring manufacturers must address a number of current issues, including more power produced by smaller engines, exotic fuels, lighter-weight materials and new cylinder-bore surfaces. With the growing selection of stock components, as well as countless custom offerings, these manufacturers are leading the way as they deliver even better quality products than just a few years ago.

Similarly, Trey McFarland of Mahle Motorsports USA, Fletcher, North Carolina, acknowledged a growing demand for custom pistons, while adding that Mahle's shelf-stock lines "are evolving to meet many previously 'custom' needs—for example, our PowerPak+ Light Weight small block Chevy pistons with .043 rings and gas ports. Also, many 'custom' options offered by other manufacturers are standard on Mahle pistons: pin fitting, skirt coating, accumulator grooves, forced pin oilers, alternative land geometries and extra-flat ring grooves."

Pistons for the traditional small and big block Chevy and small block Ford remain Mahle's bestsellers, "but we've seen strong growth in the GM LS series, Ford 5.0-liter Coyote and Chrysler 6.1- and 6.4-liter Hemi," McFarland continued. New applications for 2013 include the 6.1/6.4 Hemi, Ford Super Cobra Jet for NHRA Super Stock, Kaase Boss 9 Ford

big block and P-38 Ford small block, and vintage Ford Flathead.

"We have a custom piston program that will meet the needs of racers who require custom features," said David Chamberlin of Lunati, Olive Branch, Mississippi, "but given the extensive list of.configurations that we stock, we are able to cover most applications with parts we already have on the shelf. So while the demand for custom pistons remains steady, it tends to be secondary to our stocked items." New part numbers from Lunati include "many LS pistons for moderate-to-extreme applications. We have added a series of flat-top 2618 forged pistons in multiple compression ratios, as well as a series of dished pistons for forced induction systems."

"THE BIGGEST CHALLENGE WE FACE TODAY IS HEAT."

Most Lunati pistons offer dual forced pin oiling, and triple-wound spiral locks for easy installation and secure pin location. "Our high-compression pistons come with lateral gas porting to decrease blow-by. A second land accumulator groove captures excessive blow-by and reduces top-ring flutter. And when our customers order pistons that are oversized, they also get compensated ring grooves—that is, the diameter of the root groove increases with the diameter of the piston, to maintain the correct depth of the groove."

"Custom is a substantial part of our business," agreed Alan Stevenson of JE Pistons, Huntington Beach, California, "and we're currently developing a new ease-of-ordering program for custom pistons. We are already one of the only custom piston manufacturers to be ISO-certified." JE's shelf-stock line is substantial also, including "over 500 new part numbers for 2013. The success of our Asymmetrical design has been nothing short of spectacular. We began offering Asymmetrical pistons"—with a longer skirt on the major thrust side—"over two years ago for sport compacts, where boost and power levels were exceeding the capabilities of conventional forgings. Now we're

expanding the line to include domestic applications, beginning with the GM LS."

Alexander Califano of IASA Racing Components, Buenos Aires, Argentina, told us that custom orders account for 50 percent of production "and are growing more and more." Custom features include "full 3D cam machining of the piston top and full internal machining for weight savings. We also have dedicated forging tools to create custom pistons when the quantity ordered covers the entry cost of the process."

Evolving manufacturing processes are producing technologically advanced products to the lower- and mid-budget racer that just a year or two ago would have been custom made at considerable expense, according to one manufacturer. Photo courtesy of Mahle Clevite.

In addition to custom work, IASA specializes in "low-quantity items. We have the production flexibility to offer a short turnaround on small or custom orders. Our engineers can provide full-size drawings the same day they are ordered, and they work side by side with the customer on the final design. We also work very closely with engine builders, and with our importers and distributors, including Jacquemin Tuning in France." - arquimia

For series production, IASA is investing in "new forging tools for sport-compact turbo applications, including the VW 2.0 as well as several Japanese engines."

Superior Machining

Beeri Meza of Arias Pistons, Gardena, California, emphasized the importance of ordering custom pistons "when you need something specific," rather than attempting to modify a stock piston and possibly "compromising its integrity or durability."

Arias is currently "changing and upgrading our forgings to widen the range of custom pistons we can offer. Currently we have forgings for bores as small as 2.086 inches and as large as 5.750. We also offer billet pistons to fill in gaps or cover bores outside this range." Meza added that "the customer can't see most of the things we do to make our pistons perform under pressure." Yet characteristics such as "ring groove flatness, skirt profiles, and machine and work-holding techniques" can make the difference between a contender and a DNF.

Diamond Pistons in Clinton Township, Michigan, "produces more custom pistons than off-the-shelf types," said Ron Beaubien. "However, to protect our customers from unnecessary expenses we offer our 'one-change' initiative. This semi-custom program takes advantage of the economies of scale afforded by shelf-stock pistons, while allowing one adjustment—perhaps a change in bore size, or in the valve reliefs—for a nominal fee. Unsurprisingly, however, the demand for custom pistons continues to grow. This is chiefly caused by cylinder heads being modified from their as-manufactured state: angle milled or flat milled to unknown extents, or hand-blended combustion chambers, or shifted dowels. These modifications often necessitate full scanning and dome replication. And, of course, race teams experiment with every aspect of the piston: valve location, valve angles, load paths, rib and buttress shapes, pins, pin bosses, and so on. Inevitably, these design changes exceed the boundaries of the forging—which is why Diamond created a separate billet piston division a half-dozen years ago. First used by Pro Stock and NASCAR teams, billet pistons offer immense design opportunities."

Several manufacturers reported increasing demand for high-performance diesel parts. According to Beaubien, in fact, diesel pistons are Diamond's fastest-growing segment. He also offered this interesting perspective: "High-quality race pistons are subject to numerous operations, as you'd expect. But the order in which they are performed often makes a difference. Because the shape of the piston changes during the machining process, it is imperative that the ring grooves are machined in the correct order. Otherwise they lose their integrity—their flatness—and with it their ability to create the optimal seal."

Scott Gabrielson of Federal-Mogul, Southfield, Michigan, noted that "all of our Speed-Pro pistons are now designed, manufactured, machined and coated exclusively in-house, which has allowed us to incorporate an extensive range of enhancements to our Powerforged line." Among these are Thermal Arching Compensation (TAC) ring-groove geometries, "which offset arching of the ring pack to ensure optimal face-to-bore alignment under all operating conditions. We've also achieved a new level of control of the roundness and straightness of the pin hole. By design, the load on the piston pin causes the pin to bend, creating tremendous stress on the pin bore. This stress is magnified if the pin hole bore is not profiled to accommodate the bending of the pin. We now bore, rather than hone, our pin holes to provide significantly better oil retention and to ensure they are straight and square to the outside pin diameter.

"Our Speed-Pro hypereutectic cast pistons offers these same design features, plus thermally compensated skirt profiles to reduce wall contact; and precisely controlled 'barrel' profiles to promote the oil wedge between the skirt and cylinder wall," added Gabrielson.

Howards Cams & Racing Components of Oshkosh, Wisconsin, has a new line of premium forged 2618 small block Chevy pistons with a metric ring pack

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(1.5 mm, 1.5 mm, 3.0 mm). "They will be machined for a 4.030 or 4.125 bore," said Billy Fisher, "which with different strokes will allow you to build a 350, 383 or 396. You can also have custom work done for an additional charge"—including custom domes, based on a mold of the racer's combustion chamber. Fisher expects the new pistons to prove popular in "IMCA stock cars, sport modifieds, open modifieds, A-Mods, hobby stocks" and possibly some applications outside of circle track.

The Shape of Rings to Come

Ring manufacturers also reported a growing demand for custom engineering. Total Seal, said Jones, does "more and more custom business every day. There will always be a place for shelf parts, for people who are building a weekend bracket car, or putting an engine together from a catalog." But as a percentage of the performance aftermarket, that segment is shrinking "very, very quickly. From pulling tractors to air boats to junior dragsters and go-karts, people want to maximize what they have. They want the best possible pistons and rings, just like they want the best possible camshafts and cylinder heads—and the difference in cost isn't that much anymore."

Part of the custom market is driven by ever-larger bore sizes. "Right now," Jones continued, "we're working on projects from the middle 5's all the way up to 13 inches. We just recently made rings for a 5.220 bore." And that was a racing V8. "But now we're also testing the cross-sectional shape of the ring itself. Traditionally there have been flat rings, or barrel-shaped rings, or another handful of shapes that have been used for the past 100-plus years. Now we're questioning: There's always been an industry standard for taper, but is that really ideal for every application? We're combining shapes; a barrel on top, a little taper underneath—multiple shapes that will not only hold compression better but also scrape more oil."

For all that, it would be wrong to think that the market for shelf-stock performance rings is going away; it may

While both piston and ring manufacturers report a growing demand for custom engineering, one contact said, "There will always be a place for shelf parts." Plus, the technology that is learned from custom requests often transfers to the cataloged parts often used by amateur racers. Photo courtesy of CP-Carrillo.

indeed be shrinking, but it remains huge. According to Bill McKnight of Mahle Clevite, Ann Arbor, Michigan, "Our St. Johns facility manufactures roughly 5.3 million compression rings a month. Eighty-five percent of that is OE." But do the math, and that leaves a hair short of 800,000 genuine performance-aftermarket compression rings manufactured every 30 days. That's 9.6 million every year—and those are just compression rings; every one of them needs a second ring, and an oil-control ring, too.

"Inside the huge plant is a section that is a US joint venture with Riken," McKnight added. Based in Tokyo, Riken has manufactured piston rings since the mid-1930s, using processes first patented in 1926. Drawing on the experience of both companies, McKnight continued, "we have become very adept at manufacturing the carbon-steel rings that account for almost 50 percent of our output. The rings actually start as a large coil of wire and are re-coiled into a piston ring of very precise dimensions; using this process, we are currently making the industry's first carbon-steel Napier second ring with near-net wire configuration." These and other processes—plus the sheer size of the combined venture—allow Mahle Clevite to offer technologically advanced products to the lower- and mid-budget racer "that just a year or two ago would have been custom made at considerable expense."

For supercharged race engines burning nitro or alcohol, Mahle Clevite offers its Fire-Power compression rings. "Our PC479 alloy is a hardened, tempered ductile cast iron without a face coating," McKnight explained, "which could fracture and flake off in those extreme conditions." For less demanding environments, Mahle offers a wide range of ring sets with either carbon steel or ductile iron top rings. "

Federal-Mogul offers "two primary top-ring technologies," said Gabrielson. "We have ductile iron rings with a plasma-moly face; and HellFire rings, manufactured from our extraordinarily tough HF479 alloy. HellFire is the dominant choice for Top Fuel teams and others using blowers, turbos or nitrous. All of our top rings feature an inside bevel that promotes a positive twist. This tilts the ring face up to seal the side of the ring in the groove. On the down-stroke it helps draw the intake charge and scrapes residual oil back down into the pan. And now we're transitioning many of our top rings from ductile iron to steel. Steel provides the same ductility, with better overall wear characteristics. In the past steel was prohibitively expensive, but our volume allows us to make the change without a cost penalty to our customers.

"Our second rings are gray cast iron," Gabrielson added. Second rings do not require as much heat resistance as top rings, and so can be made from a more economical material. "These rings typically feature a reverse-twist tapered face, which offers much better oil control than a scraper-type ring."

Hastings Manufacturing of Hastings, Michigan, has released a new line for racing diesels; and continues to expand its Premium Ductile Moly Race series, which feature second compression rings with Napier OD profiling for optimal oil scraping. "The Napier ring is made of ductile/nodular iron for increased durability," noted Tom DeBlasis. The company is also expanding its SN Racing line "to include 4.600-inch and oversized bores. Our SN Racing sets include a gas-nitrided stainless steel upper ring protected by a chrome nitride PVD coating, and a Napier second ring made of ductile iron. This ring set can be used with any type of fuel and/or any power adder."

Special machining operations, according to Hastings engineer Bill Spengler, include a smooth OD finish on the wear coating and side faces of SN top compression rings, "to minimize wear of the ring, cylinder bore and piston groove." Also, "reduced axial height and tension in the oil control ring results in improved oil control while reducing friction for more usable horsepower."

"CUSTOMS ARE OUR MAINSTAY, AND I DON'T SEE THAT CHANGING ANYTIME SOON."

Piston & Ring Materials

Arias, said Meza, offers "high strength steel rings with chrome moly, or nitrided faces, depending on the application. We are also distributors for Hastings, Total Seal, and Akerly and Childs."

Spengler outlined the range of ring materials Hastings offers: gray cast iron for good scuff resistance at low cost; ductile iron for improved strength in bending; and SAE 9254 steel for "excellent bending strength, resistance to breakage and improved side face wear properties." Nitrided stainless steel provides similar advantages to 9254, plus "best available side face wear properties." Relatively new is a chrome-nitride coating applied via PVD (Physical Vapor Deposition) for "the best available scuff and wear resistance. And it can be used with any type of fuel plus supercharging, turbocharging and nitrous."

That kind of innovation is now rocking the industry. "We've had this pallet of materials that we've used to make rings," said Jones. "But now we want rings to be thinner and smaller, while we're making more horsepower; so we need a ring that can handle that heat, also. That's what's pushing the development of new materials. And it's the same with pistons. You have your traditional 2618 and 4032, but

in some new environment neither one is quite right."

For now, however, those two aluminum alloys continue to dominate piston manufacturing. Panneton clarified the differences between them. "With its high silica—i.e. glass sand—content, 4032 has good scuff resistance and allows tighter piston-to-wall clearances, at the expense of ultimate strength," he explained. "The greater the silica content, the more brittle the material, so 4032 does not lend itself to high-cylinder-pressure applications (i.e. supercharged, turbocharged, nitrous) with relatively light pistons. It has been used in some low-boost OEM applications, and even in some high-boost diesel engines, but in both cases these pistons have been made thicker and heavier than a 2618 counterpart would have to be. And because it wears out tooling quicker, 4032 is more expensive to machine. Whereas low-silica 2618 T61 is more ductile—more forgiving—so it is naturally the material used in high-cylinder-pressure applications. But the lack of silica also reduces its anti-scuffing qualities, so 2618 requires more cylinder wall clearance."

The other piston manufacturers mostly confirmed these characteristics. To 2618's capabilities, Chamberlin added "very high heat transfer, to get the heat out of the top of the piston."

Mahle, said McFarland, has formulated an extensive list of its own alloys, as well as its own versions of the popular 4032 (Mahle M124) and 2618 (Mahle MSP25) materials, "maintaining tighter tolerances of the individual alloying elements."

Federal-Mogul also uses its own "FM4032" (12 percent silicon) in its Speed-Pro Powerforged pistons. Speed-Pro hypereutectic pistons are cast, said Gabrielson, from "a super-saturated silicon material with very precisely controlled particle size and dispersion to eliminate any potential weak spots. This is a huge consideration in hypereutectic castings, so we cut and examine our castings hourly to be sure the metallurgy is correct. When done right, hypereutectic casting yields a true high-performance piston at a very reasonable price."