Survival of the Fittest Piston and Rings Continue to Evolve, Larry Carley, Underhood Service, February 2001

Stronger, lighter, thinner, more durable. That pretty well sums up the changes that have been taking place in piston and ring technology over the past decade. Typical ring sizes today are 1.2 mm for the top compression ring, 1.5 mm for the second ring and 3.0 mm for the oil ring. Some are even thinner. A few engines have top compression rings only 1.0 mm thick, and the current Buick 3800 V6 uses a narrow 2.0 mm-thick oil ring.

Engine manufacturers have been going to smaller rings because the rings alone can account for up to 40% of an engine’s internal friction. Thin, low tension rings reduce friction and improve fuel economy. They also weigh less and reduce the reciprocating mass that pounds against the piston grooves with every stroke of the piston. But low tension rings cannot tolerate much distortion in the cylinder bore, and the thinner cross section of the rings doesn’t conduct heat as efficiently as thicker rings.

Pistons are cooled partially by heat conduction through the rings to the cylinder walls, by oil splash from underneath and by the incoming air/fuel charge. The use of thinner, low tension rings reduces heat transfer via conduction causing the piston to run hotter. With a standard F-132 alloy piston, hotter means more thermal expansion and a need for greater clearance - which increases blowby and noise. So to minimize expansion, most engines today have "hypereutectic" alloy pistons and very tight piston-to-wall clearances (.001" or less). The more stable the piston, the better it’s able to maintain a tight seal. Close tolerances also make for a quieter running engine, especially after a cold start when clearances are greatest.

Hypereutectic pistons have a coefficient of thermal expansion that is about 15% less than that of F-132 alloy pistons. Because of this, they can be installed with a much tighter fit (up to .0005" less clearance depending on the application).

Hypereutectic pistons are cast from a mixture of aluminum, silicon and small amounts of other metals including copper, magnesium and nickel. Adding silicon increases the hardness of the alloy. When the mixture contains more than about 12% silicon (the "eutectic" point), the extra silicon no longer remains dissolved in the aluminum and begins to form hard, wear-resistant particles when the metal cools.

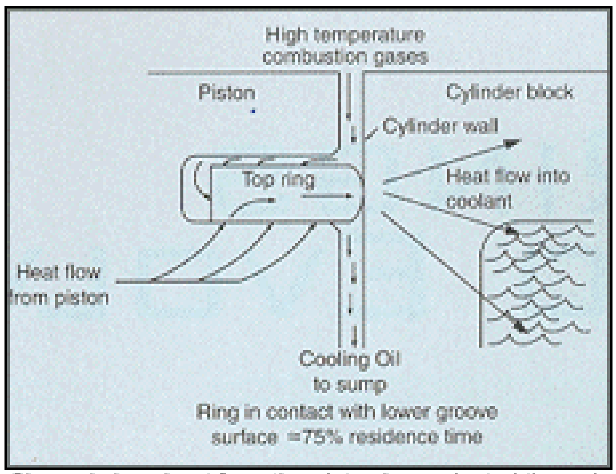
Hypereutectic alloys are those that contain more than 12% silicon, typically as much as 16-18% silicon. By comparison, a conventional F-132 piston alloy contains 8.75-10.25% silicon. The additional silicon is what gives hypereutectic pistons their extra hardness and improved wear resistance.

Casting a high quality hypereutectic piston isn’t easy because the silicon must be evenly dispersed throughout the aluminum as the metal cools. Particle size must also be carefully controlled so the piston does not become brittle or develop hard spots making it difficult to machine. Some pistons also receive a special heat treatment to further modify and improve the grain structure for added strength and durability.

Machining hypereutectic pistons requires diamond tooling. The hard particles of silicon wear out tooling much more quickly than standard alloy pistons, which adds to their manufacturing cost and makes them more expensive than standard alloy pistons.

Because of their higher cost, some engine rebuilders may substitute standard alloy pistons for hypereutectics when rebuilding a late model engine. This is not recommended because standard pistons are not as durable. The tensile strength is about the same, but standard pistons lack the high temperature fatigue strength of the hypereutectic alloy and can suffer ring pound out problems in demanding applications.

Weight is another factor to consider. Hypereutectic alloys are only about 2% lighter than F-132 alloys. But because of the increased strength of the material, hypereutectic pistons can be designed with thinner sidewalls (up to 0.5 mm thinner) to reduce overall piston mass by as much as 10% or more depending on the application. A lighter piston reduces the reciprocating mass of each piston assembly, which means smaller counterweights can be used on the crankshaft to reduce stress and vibration within the engine. Lighter pistons can also handle higher rpms with less stress on the rods, crankshaft and block.



Shown is how heat from the piston is conducted through the rings to the cylinder wall. Narrower rings cool less efficiently causing the piston to run hotter.

Many production pistons today look like racing pistons from a decade ago. Engineers refer to something called the piston "X-factor," which is the ratio of piston mass in grams to piston diameter in centimeters. Ten years ago, the average production piston had an X-factor of 0.65. Today, the X-factor is down to 0.42 to 0.43.

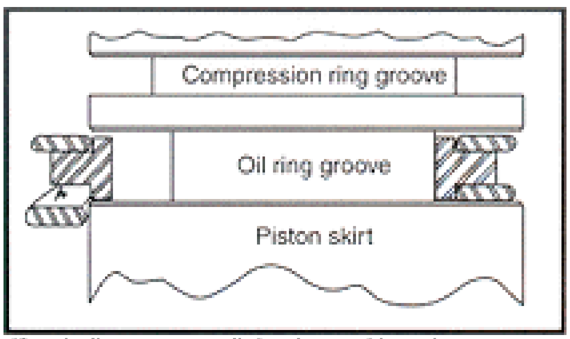
In addition to being lighter, many pistons are also shorter because of reduced block height and longer connecting rods. The distance between the top of the piston and centerline of the wrist pin (called the "compression height") keeps getting shorter and shorter. This too, affects the piston’s ability to manage heat by retaining more heat in the top of the piston.

Some aftermarket pistons are now available with wrist pins that have been relocated upward slightly to compensate for resurfacing on the block and heads. This, says the suppliers of such pistons, is a better solution than shaving the tops of the pistons. Shaving the top of the piston reduces the depth of the valve reliefs, which may leave too much compression and increase the risk of detonation.

Coated Skirts

Something else you'll find in a growing number of late model engines is graphite moly-disulfide coatings on piston skirts to improve scuff resistance. Engines with coated pistons include Ford's 4.6L V8, Chrysler's 3.2L, 3.5L, 3.8L and 4.0L, and GM's 3.1L V6.

Replacement pistons for these engines or any other that has coated pistons should be the same. Coated pistons are also available for many other older engines as well, and can be used to provide added scuff protection in "problem" applications.



If a shallow groove oil ring is used in a deep groove piston, installation of the ring onto the piston will be difficult. The ring assembly will "pop off" the piston as shown.

Skirt coatings also allow tighter clearances between the piston and cylinder to reduce piston rocking and blowby. No additional piston clearance is required to compensate for the added thickness of the coating (which may vary from .0008" to .0012"). In other words, the recommended final bore size is the same for a coated piston as an uncoated piston. The graphite/ moly coating prevents the tighter-fitting piston from scuffing.

Reducing Emissions

To reduce hydrocarbon (HC) emissions, the rings in many late model engines have been moved up closer to the top of the pistons. A decade ago, the land width between the top ring groove and piston crown was typically 7.5 to 8.0 mm. Today that distance has decreased to only 3.0 to 3.5 mm in some engines.

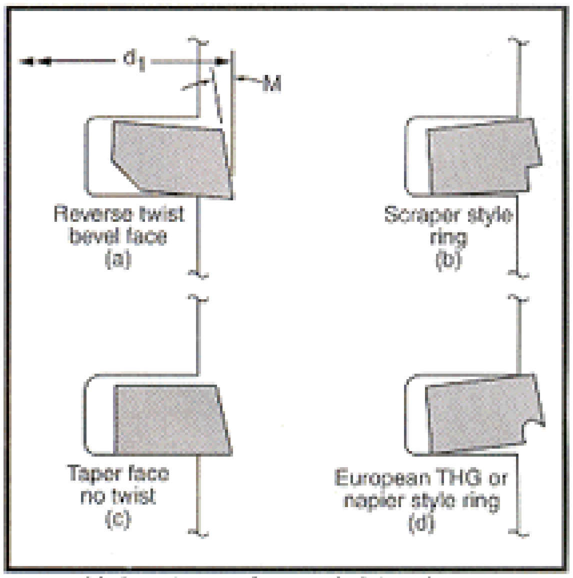
Relocating the rings closer to the top of the piston reduces the size of the crevice just above the top compression ring. Fuel vapor that enters this area during the piston's compression stroke often fails to burn completely when ignition occurs. A few droplets of fuel may not seem like much, but every drop adds up when it comes to meeting hydrocarbon emission requirements.

Moving the rings up on a piston reduces emissions, but it also exposes the top ring to more heat from the combustion chamber. The reduced thickness of the land area between the first groove and top of the piston also weakens the piston, increasing the risk of piston failure. Hypereutectic alloys have the extra strength needed to resist failure in this critical area, and the hard silicon particles provide a wear-resistant surface that prevents the top ring from pounding out the groove.

On some pistons (GM 3800 supercharged V6, for example), the crown and top ring groove are also anodized to improve durability and resistance to microwelding. Microwelding occurs when high combustion temperatures cause tiny particles of aluminum to melt on the piston and redeposit themselves on the ring.

Relocating the top compression ring higher on the piston also means the ring itself must be made of a more heat resistant material. The top rings on many engines today run at close to 600° F, while the second ring is seeing temperatures of 300° F or less. Ordinary cast iron compression rings that work great in a stock 350 Chevy V8 can't take this kind of heat. That's why many of these late model engines have steel top rings. Steel is more durable than plain cast iron or even ductile iron, and is required for high output, high load applications including turbocharged and supercharged engines as well as diesels and performance engines.

When one of these late model engines with steel rings is reringed or rebuilt, only steel replacement rings should be used. One way to identify the type of original equipment ring is to twist the ring after it has been removed. A steel ring will bend while a cast iron ring will break.



Various types of second piston rings.

Cast iron rings are still a popular choice for many older engines as well as "economy" rebuilds that are suitable for light-duty, everyday driving. Most late model applications, though, require more durable rings such as ones faced with chrome or moly. For applications where an engine is subjected to higher loads and operating temperatures, moly-faced rings usually provide the best wear resistance. Molybdenum also provides great scuff resistance and is porous so it retains oil to keep the ring lubricated. Moly also has a higher melting point than chrome or plain cast iron, which enables it to survive under the harshest operating conditions. But chrome rings are still a good choice for engines that are operated in dusty environments because chrome is very dense and won't trap and hold contaminants like moly can. And compared to plain cast iron, chrome rings can cut wear by more than 50%.

Nitrited rings, which are used in many Asian engines, also provide improved scuff and wear resistance. But the nitriding process uses cyanide, which poses environmental concerns for ring manufacturers. So moly and chrome are the preferred facing materials in North America.

Replacement rings, in most instances, should have the same or better type of facing material than the original to maintain the durability and scuff resistance that was originally designed into an engine. Substituting plain cast iron rings in an attempt to hold down costs will sacrifice those advantages.

Changes In Ring Clearances

To improve ring sealing, some late model engines such as Ford 4.6L and Corvette LS1 are now using a wider end gap on the second ring. The end gap on the second ring is 1.5 to two times that of the top ring. The actual specification may range from .006 to .013" greater than the top ring depending on the application. The theory here is to treat the rings as a dynamic rather than static assembly.

When the combustion pressure over the top ring is greater than the pressure between the top and second ring, it forces the top ring downward and outward to seal against the piston groove and cylinder. But if pressure builds up between the two rings, it can prevent the top ring from sealing and increase blowby. One way to maintain the pressure differential is to open up the end gap of the second oil ring. A wider end gap provides an escape route for blowby gases that get past the top ring. This prevents pressure from building up so the top ring will continue to provide maximum sealing.

On some pistons, an "accumulator groove" is machined into the piston between the top and second ring to increase the volume of space between the rings. The accumulator groove helps reduce the buildup of pressure until the blowby gases can escape through the end gap in the second ring.

What you may not know is that the second ring is not really a compression ring but an oil control and vacuum ring. Many second rings have a reverse-twist, taper face design that allows the ring to glide over the cylinder wall during the piston upstroke. When the piston reverses direction, the sharp edge of the ring is forced out against the wall and acts like a squeegee to wipe off the excess oil. At the same time, the second ring seals against the wall so the piston can pull as much vacuum as possible on the downstroke.

On many late model engines, the second ring is a taper faced, corner groove, positive twist design. The lower outside diameter of this type of ring has a scraper groove that collects oil and also acts like an accumulator to reduce inter-ring pressure. On many European engines, the second ring has a shallow groove along the lower outside diameter. This is called a "THG" or "Napier" type ring.

When reverse-twist taper-face rings are used, the piston usually has a step groove on the third piston land to form a reservoir for the oil that’s scraped off, and to add volume to the area between the second ring and oil ring to control inter-ring pressure. The step groove is not needed if the second ring has a scraper groove or Napier groove on the underside of the outside diameter.

As for oil rings, most North American and Asian vehicle manufacturers are using a traditional three-piece oil ring. The Europeans, on the other hand, prefer a one-piece oil ring with an expander behind it.

Ring Installation Errors

Installation is just as important as the type of pistons or rings that are used in an engine. One of the most common installation errors is installing one or more rings upside down. If only one second oil ring is accidentally installed upside down in a V8 engine, it can double the engine's oil consumption! If every second ring on all the pistons are reversed, the engine will have an unquenchable thirst for oil - which may be mistakenly blamed on improper ring break-in, seating or cylinder wall finish. Rings are usually marked with a dot, which must always face up. If no mark is provided, rings with a bevel on the inside diameter must be installed with the bevel facing up. On rings with no mark and a groove on the outside diameter, install the rings with the groove toward the bottom of the piston.

Another common error is spiraling rings onto a piston. This will usually deform the ring, which can affect ring rotation and seating. Always use a ring expander, and make sure the expander has a stop so the ring is not overextended.

Ring and groove depth should be compared prior to installing the rings to make sure the rings are the right ones for the piston. If shallow groove rings are installed on a deep groove piston, the rings will tend to pop off the piston before the piston is installed in the engine. If rings designed for a deep groove piston are installed on a shallow groove piston, the rings will bottom out and jam against the cylinder.

Ring side clearances and end gaps should always be measured after the rings have been installed to make sure the rings fit the grooves and cylinders correctly.

Rings can be damaged during installation if the lower lip of the ring compressor is nicked, rolled over or bent. For this reason, the underside of the ring compressor should be checked frequently for damage.

Finally, adequate ring and cylinder lubrication is essential to provide for proper ring seating and protection when the engine is first started. Scrubbing out the cylinders with hot soapy water after the block has been honed is also essential to remove all the abrasives and other contaminants that can damage new rings.