# Expansion Coefficient of Aluminum Pistons– Forged vs Cast Pistons: A Literature Search

Rev. 3 Fred Moreno, Chris Howden 31 March 2009

**Summary**: Expansion coefficient is a function of the silicon content of the aluminum alloy. Forging requires alloy compositions lower in silicon content. These have higher expansion coefficients than cast alloys. So it is not the forging, but the alloy selected that dominates the expansion coefficients and thus the piston to cylinder clearances required. More silicon means lower expansion coefficient. But hardness and brittleness go up as silicon content goes up.

Modern cast pistons have lots of silicon content. These alloys are termed hypereutectic (more than eutectic mixture which is 12% silicon in aluminum).

**eu·tec·tic** (yōō-tĕk'tĭk) adj.

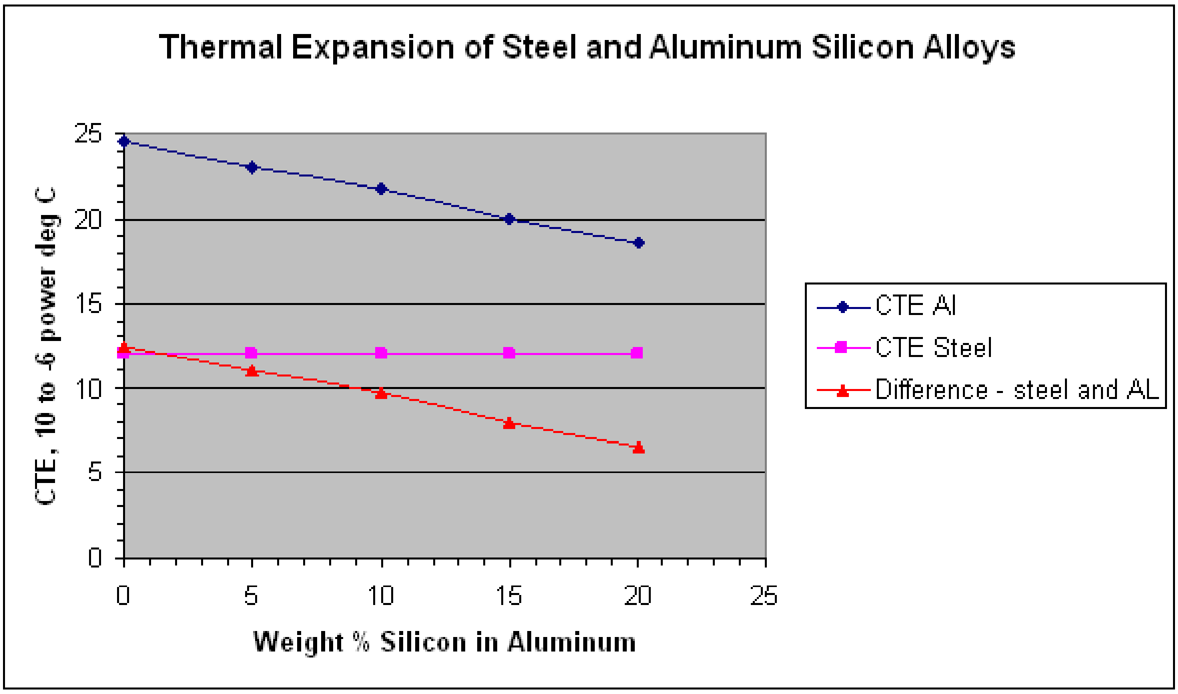
1. Of, relating to, or formed at the lowest possible temperature of solidification for any mixture of specified constituents. Used especially of an alloy whose melting point is lower than that of any other alloy composed of the same constituents in different proportions.
2. Exhibiting the constitution or properties of such a solid.

n.

1. A eutectic mixture, solution, or alloy.
2. The eutectic temperature.

Because higher silicon contents make the alloy harder and more brittle, alloys used in forging are necessarily **lower** in silicon. The resulting alloy is tougher, sometimes stronger, more resistant to detonation damage and more suited to extreme use such as racing. BUT it has a higher expansion coefficient requiring MORE piston to cylinder clearance to allow for the piston to grow when it heats. This is particularly true when using a steel or iron bore since steel and iron have lower thermal expansion coefficients than aluminum.

For aluminum pistons operating in steel cylinders, the key figure of merit is the difference in thermal expansion coefficients between steel and aluminum. I created an Excel spread sheet that computes this value (using an average figure of 12 for steel which ranges from 11 to 13) and then plotted the result which is shown below.



The key is the red line, the difference in thermal expansion between steel and aluminum. Note that it ranges from 12 for zero percent silicon to 8 for 12% silicon (the eutectic ratio) and down to 7 for 15% silicon, a slightly hypereutectic mix. So we can see that the thermal expansion coefficient reduces to 7/12 = 58% in going from no silicon to 15% silicon. It is down to 50% if you go out to 20% silicon.

This suggests that the piston to bore clearance can be reduced by this much if the silicon value is raised from zero to 15%. In other words, **silicon content makes a big difference requiring that adjustments must be made in piston to bore clearance as the amount of silicon in the alloy is changed**.

The advantages of cast pistons with higher silicon alloy are

- lower expansion coefficient,
- less bore clearance,
- less noise on start up when pistons are cold, and
- better long term wear in "normal" applications because the excess silicon hardens surfaces.

The advantages of forged pistons with lower silicon content are

- greater toughness,
- resistance to cracking, and
- Tolerance of abuse, and detonation
- **but** at the cost of greater required piston to cylinder clearance to accommodate the higher thermal expansion coefficient.

The following was extracted from one of the articles cited in the attachment (emphasis added).

> With Hypereutectic pistons [cast], the primary reason for having all of this free silicon is to reduce piston ring groove wear. This allows piston designers to move the top compression ring much farther up the side of the piston (where combustion temperatures are much hotter), and run much smaller, thinner piston ring lands (the metal section separating the ring grooves).

**The conclusion**: be cautious with tight piston to cylinder clearance when using low silicon aluminum alloys typically used in forged pistons.

Below are presented articles from various sources adding additional information and background on the topic of forged versus cast pistons. A discussion of hypereutectic pistons is also included.

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http://www.carcraft.com/techarticles/piston_ring_technology/index.html

# Piston And Ring Technology

**Better Materials, Shaving Weight, Improved Manufacturing Precision, Computer-Aided Design, And CNC-Machining Processes**

Repeated cycles of searing combustion heat alternating with cool incoming air and fuel, extreme load reversal, thrust forces that slam the pistons into the cylinder walls—it's quite amazing that aluminum pistons can survive in a performance engine at all. That they do is a tribute to today's aftermarket material science and advanced manufacturing techniques. Technology has advanced to the point that what just a few years ago were considered custom "race-only" parts are now available at relatively affordable prices for even everyday performance use. Big-time companies like Federal Mogul/Speed-Pro are introducing new-generation lightweight mass-produced parts, while on the extreme high-end, new-tech niche manufacturers—such as HTC Products and CP Pistons—are working with advanced design processes and exotic materials to merge rocket science with race science.

Developments have focused on better materials, shaving weight, improved manufacturing precision, computer-aided design, and CNC-machining processes. Better materials and weight savings go hand in hand; stronger materials can be made lighter without sacrificing durability. And tighter manufacturing tolerances ultimately translate into better, closer-fitting parts that can be installed with reduced clearances for better sealing. Computer-aided design combined with finite element analysis allows "testing" the part before it actually leaves the drawing board, ensuring it is both as light and as strong as possible. With CNC milling, custom pistons are easier than ever to make, with lead time often in days instead of weeks and months. And what used to be custom orders are now in many cases in-stock items.

**Pistons**

The first step up from the common cast piston is the hypereutectic casting, which is strengthened with additional silicon content added to the aluminum brew. As with a conventional cast piston, a properly designed hypereutectic piston permits relatively tight piston-to-wall clearances, making for less noise under cold-start conditions.

All cast pistons—be they standard or hypereutectic—are made by pouring melted aluminum into a mold that shapes the slug into a piston. In contrast, forged pistons are formed using a giant press that takes a block of metal and pounds it into shape under thousands of tons of pressure. The tooling needed to do this is much more expensive than the tooling used to make a casting, and it wears out quicker. This makes forged pistons more costly than castings.

However, forgings have inherent advantages in terms of density, ultimate strength, and durability. Forging eliminates metal porosity, improves ductility, and generally allows the piston to run cooler than a casting. Within reason, forgings can be lightened without adversely affecting structural integrity. However, forged pistons expand and contract more under changing temperatures, so they traditionally require greater piston-to-wall clearance than cast pistons. In recent years, CNC-machining processes, diamond tooling, and careful attention to piston skirt profiling has given piston makers the ability to finely adjust skirt contact areas for more even loading. Barrel-type profiles now accommodate greater expansion at operating temperature. One result is that today's short-skirted pistons have better contact areas than the old long-skirt designs, and wear is reduced even as piston-to-wall clearances are tightened up.

Forged pistons are generally made from one of several different aluminum alloys, with each offering different benefits depending on the application. The two most popular alloys are 4032 and 2618. Speed-Pro typically uses VMS-75, which is fairly close to 4032—both contain about 11 percent silicon, which helps with ring groove and skirt durability. These are the best choice for applications expected to have decent longevity, such as street vehicles and entry-level bracket racing and oval track combos. Although 2618 has better high-temperature characteristics, it contains virtually no silicon. This material expands and contracts more, so greater bore clearances are needed to prevent scuffing. Pistons using 2618 are best suited to nitrous, blowers, or higher end race applications where frequent inspection and replacement are not a problem.

A recent innovation is "Ultralloy," a secret patented ceramic-aluminum alloy presently available from HTC Products, a premier manufacturer and distributor for most brands and types of cranks, rods, pistons, and rings. The silicon particles in Ultralloy have unprecedented uniformity in terms of their size, shape, and dispersion in the aluminum matrix. The new alloy's strength is on par with titanium (and costs less) and parts can be made much lighter.

One of the most important advantages of forged pistons is what happens at the point of piston failure. Under extreme conditions—like detonation—forgings tend to "go plastic" and fail gradually. You generally have time to replace them before the entire engine is toast. Hypereutectics, although relatively strong in terms of ultimate tensile strength, have less ductility and are prone to fracture when their limits are exceeded. However, a lightweight hypereutectic piston specifically designed for high-performance use can withstand considerable cylinder pressures if the tune is right. When considering which style of piston is right for your application, you should consider how much abuse the piston will see, your budget, and the need to remain competitive in your form of racing. Sustained heat is the biggest piston-longevity limiter.

**Rings**

Piston rings perform a number of important functions. They seal the gap between the piston and cylinder wall to prevent combustion gases from blowing by into the crankcase. They stabilize the piston as it travels up and down in the bore. They help cool the piston by transferring heat into the engine block. And they scrape oil off the cylinder walls. That's a tall order, and in recent years the theory on how to make rings best carry out these tasks has undergone revision.

Old-school thinking followed a brute force approach: Make everything as rigid as possible to force the rings into contact with the walls. Today, the trend in current production and racing engines is towards a more flexible ring package that better conforms to the cylinder wall. Back in the musclecar days, most production engines used a 5/64-5/64-3/16-inch package. The 1/16-1/16-3/16-inch packages were for all-out racing. These days, Detroit automakers and many racers are gravitating toward even thinner "metric" rings. Standard-tension oil rings have been replaced by low-tension rings. Many of the new ring packages feature reduced radial wall thickness. Besides decreasing friction, this makes for a more stable package—assuming the piston rings, piston profile, and cylinder wall finish take advantage of these improvements. In the custom piston world, most build-to-order pistons can be ordered for reduced radial thickness rings; otherwise, spacer stock can be used to convert conventional pistons.

Ring groove design is far more important than it may appear at first glance. Properly designed ring grooves have a small degree of vertical uplift, which compensates for uneven temperature growth as the piston reaches operating temperature. Ring groove smoothness is likewise extremely important; any waviness or roughness causes poor ring seal and can lead to microwelding—a destructive situation where, under extreme pressure, the rings momentarily attach themselves to high spots on the ring groove. There also should be a small radius where the vertical and horizontal portion of the ring grooves meet. Pistons without this radius are more prone to groove distortion and ring land breakage.

Thinking on piston ring gaps has also changed. In the old days, second ring gap specs were tighter than those for top rings because they didn't see as much heat. But this didn't account for inter-ring gas-pressure buildup between the top and second rings. If the pressure between these rings equals or exceeds the pressure above the top ring, it can cause the top ring to lift off the bottom of the piston ring groove and lose contact with the sealing surfaces. It also inhibits the ring's ability to transfer heat from the piston. To keep inter-ring pressure from becoming a problem, the current trend is to create an easy escape path for the built-up pressure by gapping the second ring larger than the top ring. Another benefit is that because gas pressure is now directed downward towards the sump, any oil that has collected in the ring pack areas will go with it.

Of course, normal ring wear causes the gaps to open up, allowing more combustion gases to escape. At least one ring manufacturer—Total Seal—offers gapless rings. Traditionally, these gapless rings went in the second groove along with a conventional top ring, but ring technology refinements plus the new thinking on ring sealing has led Total Seal to revise this installation scheme and introduce a new line of gapless top rings that achieve significantly less blow-by under real-world running conditions.

The ultimate in ring seal is drilling the pistons for gas ports. Compression rings normally need about 0.002-0.004-inch (vertical) ring-to-groove side clearance to allow cylinder pressure to get behind the ring and force it to seal against the groove and cylinder wall. Gas ports apply combustion pressure directly to the back of the ring, allowing the virtual elimination of side clearance. Since the ring is restrained by the groove itself, there's less opportunity for high-rpm ring flutter. Very thin, narrow, and lightweight 0.043-inch–thick rings are needed to reap gas-porting's full benefits. Gas ports work best with short piston-compression heights (under 1.200 inches) on engines running 7,000 rpm or higher. The major drawback is that all this positive pressure greatly shortens ring life, so it's not recommended for street use.

No matter the specific thickness and configuration, most high-performance and racing engines now use moly-faced rings in the top groove. Plasma-sprayed moly over a ductile-iron base material is the preferred choice, but steel is becoming more popular because it's at least as strong and easier to machine.

The clearest statement of the difference between cast and forged is the article below. These and other articles suggest that forged pistons are tougher and more suitable for racing and detonation tolerance than cast pistons, but suffer from larger expansion coefficients which require larger cylinder clearances than cast pistons. Engines with forged pistons are therefore much more sensitive to warm up and break in procedures which must be done much more carefully to prevent the expanding forged piston from growing faster than the cylinder leading to piston grabbing, scuffing, and ring damage that can lead to ring flutter and oil loss out the breather under some operating conditions.

http://www.glmmarine.com/castvsforged.html

Pistons: Cast vs. Forged

GLM offers an extensive line of pistons for all major brands and models of outboard engines. GLM pistons, like OEM pistons, are cast as opposed to forged.

We have all heard the advantages of forged pistons. However, when you consider the disadvantages of forged pistons it becomes very clear why GLM cast pistons are the ultimate pistons for your rebuilding and repair projects.

The major disadvantages to forged pistons are actually a result of the forging process itself. Forging results in a piston that is considerably heavier, than cast pistons, and is limited in the aluminum alloys that can be used to produce the piston. Additionally, the forging process also limits the design configuration of the piston itself.

The forging process and its limited choice of aluminum alloys result in a dramatically higher expansion rate for the forged piston. This means that the set up characteristics are very different from the original engine manufacturers' and that break-in and warm up periods are crucial for the forged piston.

An example of the dramatic expansion of forged pistons is the piston skirt clearances in the cylinder. A typical cast piston has a skirt clearance [outboard motors] of approximately .0007 to .0009. A forged piston has a skirt clearance of .005 to .007. The forged piston has 10 times more slop in the cylinder. This results in less ring stability against the cylindrical wall, more piston noise and extra blowby.

In all fairness, after the forged piston has reached operating temperature, its dramatic expansion makes up for these extra clearances. However, this should remind us of the typical customer that a dealer services. Can we expect the casual weekend boater to strictly observe the extended break in period and the critical warm up procedures required for a forged piston? Let your own experience answer this question.

Most forged pistons are quality products, but they are better suited to racing and professional applications.

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## Hypereutectic piston

### From Wikipedia, the free encyclopedia

"Hypereutectic" means over eutectic. The word eutectic refers to a condition in chemistry when two elements can be alloyed together on a molecular level, but only up to a specific percentage, at which point any additional secondary element will retain a distinct separate form.

Although internal combustion engine pistons commonly contain trace amounts (less than 2% each) of copper, manganese, and nickel, the major element in automotive pistons is aluminium due to its light weight, low cost, and acceptable strength. The alloying element of concern in automotive pistons is silicon. Gold and silver have no eutectic point, which means they can be alloyed together in any ratio, however, when silicon is added to aluminium they only blend together evenly on a molecular level up to approximately a 12% silicon content. For the purposes of this discussion, silicon in this context can be thought of as “powdered sand”. Any silicon that is added to aluminium above a 12% content will retain a distinct granular form instead of melting. At a blend of 25% silicon there is a significant reduction of strength in the piston alloy so stock hypereutectic pistons commonly use a level of silicon between 16% and 19%. Special moulds, casting, and cooling techniques are required to obtain uniformly dispersed silicon particles throughout the piston material.

**The reason for their development**

Most automotive engines use aluminium pistons that move in an iron cylinder. The average temperature of a piston crown in a gasoline engine during normal operation is typically about 300C (600 degrees Fahrenheit) and the coolant that runs through the engine block is usually regulated at approximately 90C (190 degrees F). Aluminium expands more than iron at this temperature range so for the piston to fit the cylinder properly when at a normal operating temperature, the piston must have a loose fit when cold.

In the 1970s increasing concern over exhaust pollution caused the U.S. government to form the Environmental Protection Agency (EPA) which began passing legislation that forced automobile manufacturers to introduce changes that made their engines to run cleaner. By the late 1980s automobile exhaust pollution had been noticeably improved but more stringent regulations forced car manufacturers to adopt the use of electronically controlled fuel injection and hypereutectic pistons. Regarding pistons, it was discovered that when an engine was cold during start-up, a small amount of fuel became trapped between the piston rings. As the engine warmed up, the piston expanded and expeled this small amount of fuel which added to the amount of unburnt hydrocarbons in the exhaust.

By adding silicon to the piston's alloy, the piston expansion was dramatically reduced. This allowed engineers to specify a much tighter cold-fit between the piston and the cylinder liner. Silicon itself expands less than aluminium but it also acts as an insulator to prevent the aluminium from absorbing as much of the operational heat as it otherwise would. Another benefit of adding silicon is that the piston becomes harder and is less susceptible to scuffing which can occur when a soft aluminium piston is cold-revved in a relatively dry cylinder on start-up or during abnormally high operating temperatures.

The biggest drawback of adding silicon to pistons is that the piston becomes more brittle as the ratio of silicon is added. This makes the piston more susceptible to cracking if the engine experiences pre-ignition or detonation.

**Performance replacement alloys**

When auto enthusiasts want to increase the power of the engine they may add some type of forced induction. By compressing more air and fuel into each intake cycle, the power of the engine can be dramatically increased. This also increases the heat and pressure in the cylinder.

The normal temperature of gasoline engine exhaust is approximately 650C (1200F). This is also approximately the melting point of most aluminium alloys and it is only the constant influx of ambient air that prevents the piston from deforming and failing. Forced induction increases the operating temperatures while “under boost” and if the excess heat is added faster than engine can shed it, the elevated cylinder temperatures will cause the air and fuel mix to auto-ignite on the compression stroke before the spark event. This is one type of engine knocking that causes a sudden shockwave and pressure spike, which can result in an immediate and catastrophic failure of the piston and connecting rod.

The “4032” performance piston alloy has a silicon content of approximately 11%. This means that it expands less than a piston with no silicon, but since the silicon is fully alloyed on a molecular level (eutectic), the alloy is less brittle and more flexible than a stock hypereutectic “smog” piston. These pistons can survive mild detonation with less damage than stock pistons.

The “2618” performance piston alloy has less than 2% silicon and could be described as hypo (under) eutectic. This alloy is capable of experiencing the most detonation and abuse while suffering the least amount of damage. Pistons made of this alloy are also typically made thicker and heavier because of their most common applications in commercial diesel engines. Both because of the higher than normal temperatures that these pistons experience in their usual application and the low-silicon content causing the extra heat-expansion, these pistons have their cylinders bored to a very loose cold-fit. This leads to a condition known as “piston slap” which is when the piston rocks in the cylinder and it causes an audible tapping noise that continues until the engine has warmed to operational temperatures. These engines should not be revved when cold, or excessive scuffing can occur.

**Forged versus Cast**

When a piston is cast the alloy is heated until liquid, then poured into a mould to create the basic shape. After the alloy cools and solidifies it is removed from the mould and the rough casting is machined to its final shape. For applications which require stronger pistons, a forging process is used.

In the forging process the rough casting is placed in a die set while it is still hot and semi-solid. A hydraulic press is used to place the rough slug under tremendous pressure. This removes any possible porosity and also pushes the alloy grains together tighter than can be achieved by simple casting alone. The result is a much stronger material.

Hypereutectic pistons can be forged but typically are only cast because the extra expense of forging is not justified when cast pistons are considered strong enough for stock applications.

Aftermarket performance pistons made from the most common 4032 and 2618 alloys are typically forged.

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http://www.hoon.tk/tech_tips/pistons.html

Discussion of cast vs forged pistons.  Key highlights marked in red

## *Tech Speak: Forged or Cast?  Piston Basics!*

### CAST AND FORGED PISTONS

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The majority of original equipment and aftermarket pistons are manufactured through casting.  The technical description is 'gravity die casting'.  However for the sake of simplicity, a cast piston is manufactured by pouring molten aluminium/silicon alloy into a mold.  Forged pistons differ fundamentally in manufacturing and inherent character.  As opposed to casting, the forging process basically takes a lump of billet alloy and stamps the shape of the piston from a die.  Of course, both manufacturing procedures are a lot more complex and intensive that this simple analysis, but you get the broad picture.

Casting and forging results in two different types of piston.  A die for forged piston must be designed so it can easily be removed and, as a result, the forged blank (or unfinished piston) has a relative simple shape.  Casting can achieve a more complex blank and, therefore, facilitate lightweight construction.  Also, due to relative manufacturing procedures, forged pistons tend to be more expensive than cast items and forged 4.9 and 5.0 litre Holden V8 pistons have been traditionally scarce, in terms of availability.  Although 5.7 litre Holden Chev units ca be sourced as off-the-shelf product, you may need to have suitable 304/308 forged pistons custom made, with a tidy price to match.

### CAST PISTON MATERIALS

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No matter which piston you use, and no matter which engine a piston goes into they are all made from a combination of both aluminium and silicon.  It is the amount of silicon though, which determines the pistons overall strength verses wear resistance properties.  **Silicon also controls the rate of expansion of the piston as the material becomes hotter (the less expansion then better!).**  Silicon content also markedly affects actual material hardness.  More Silicon makes the piston much easier to machine-in the manufacturing phase.  There are traces of many other metals in cast pistons, including copper, nickel, manganese and magnesium, all of these adding somewhat to the overall behaviour and strength of the piston.

## HYPEREUTECTIC AND EUTECTIC

Pretty much the catch words in cast pistons towards the end of last decade, Hypoeutectic, Eutectic and Hypereutectic are metallurgical terms which describe little more than the amount of silicon present in the piston material and the way in which it is structured (uniformly) in the piston itself. Hypoeutectic describes a molten mixture of alloy which contains a low quantity (up to around 10 per cent) of silicon to aluminium ration where the silicon can completely dissolve. Manufactures don't use Hypoeutectic alloy much for cast piston construction, so this is the last we'll mention of it.

The most common piston found in production car engines, is constructed from a Eutectic alloy. The term Eutectic mean that the piston alloy contains around 12.5% silicon. This is just about the point of total dissolved silicon saturation. With older piston designs which have conventional ring lands, there is little need to have any more than this simple, reliable material which has served the industry so well for so long. In fact all the worldwide passenger car engine manufactures we know of still use the 12.5 per cent alloy.

Hypereutectic alloy is pretty damn similar, but has a much higher degree of silicon in its makeup, something around the 16-18 per cent mark. What this actually achieves in the piston-manufacturing process is a high degree of free (undissolved) silicon in the end piston. The silicon/aluminium ratio affect the metal's character. The higher silicon content in the Hypereutectic alloy lends itself to improved scuff resistance and, importantly, a relatively low expansion rate.

Early in the peace it was common for US forged-piston materials to contain only 7 per cent silicon in their make-up. This led to high temperature expansion rates, making engines sound 'rattly' when started cold. The Germans came to the rescue here with new materials for forged pistons which did away with the undesirable expansion rates, by containing a much more acceptable 14 per cent silicon content. As some top-level German cars have forged pistons standard (BMW V8, V12 ect) it was a requirement that these engines remained smooth and quiet, even when cold - hence the development of better materials. Now, a lot of the aftermarket forged-piston manufactures have caught on and are offering the 'quieter' high silicon content alloy.

With Hypereutectic pistons, the primary reason for having all of this free silicon is to reduce piston ring groove wear. This allows piston designers to move the top compression ring much farther up the side of the piston (where combustion temperatures are much hotter), and run much smaller, thinner piston ring lands (the metal section separating the ring grooves). The reason piston designers want to do this is that it allows a lighter piston to be produced, and also has dramatic results in changing engine emission characteristics. As emission laws become tougher, it will be commonplace to find true Hypereutectic pistons in road engines. It must be added though, that Hypereutectic pistons are not automatically stronger than conventional Eutectics. Their main advantages being reduced chance of ring/grove welding and reduced piston ring grove wear. If higher piston strength is needed, then generally, a piston manufacturer will ass more copper and nickel to the alloy to gain extra high temperature strength.

All metallurgy aside, it is not so much what material your pistons are made from but their physical design that is will determine ultimate durability and whether they are going to break/seize.

## CAST VERSUS FORGED

This is an age-old problem for engine designers. At what sort of power level is it necessary to change from a conventional cast Eutectic/Hypereutectic piston to a forged item? According to ACL's chief piston engineer, the only real disadvantage of a cast piston (in high output situations) is in the case of a piston failure, a cast items is more likely to shatter and damage the engine, as a whole, more than a forged piston.

A big advantage with forged pistons is they generally result in a more ductile material, with the effect being the piston can take a higher level of detonation before failing. As far as I am concerned, this is not such a huge bonus as you engine should be tuned not to detonate in the first place. In extremely high rpm/high horsepower applications, the great strength of the forged piston can add reliability, with ACL recommending they be used once power levels rise past about 80hp per litre of engine capacity.  This gives us around 450hp in a 5-litre Commodore before even thinking of changing to a forged piston.

## CONCLUSION

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All of ACL's performance orientated Race Series V8 pistons include some tricky design technology such as integrated oil drain back slots and a pressure balancer groove in the top ring land to help reduce ring land breakage, in the case of detonation.  In the instance if building a mildly supercharged 5 litre V8, or pushing for 450hp out of a normally aspirated engine, the is probable little advantage in investing large sums of money in forged pistons, when a correctly-tuned engine with either standard Eutectic items or modern design Hypereutectic (ACL Race Series or similar) pistons will give the same power output and reliability levels.

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http://www.carcraft.com/techarticles/ccrp_0810w_mahle_piston_alloy_comparison/index.html

Discussion from an after market piston manufacturer which again discusses differences in expansion coefficients cast vs forged.  Alloy for forging is lower silicon and has higher expansion coefficient.

Recently Mahle showed us that there are distinct differences between their 4032 and 2618 alloys. The choice to use one over the other depends on your project. Are you building a street/strip machine or an all out racer? Choosing the wrong one can be devastating. To better understand, we'll let MAHLE explain.

Chrysler/Hemi

Ford Big-Block

LS7

4032 is a high-silicon, low-expansion alloy. Pistons made from this alloy can be installed with tighter piston to bore clearance, resulting in a tighter seal with less noise. 4032 is a more stable alloy, so it will retain characteristics such as ring groove integrity, for longer life cycle applications. Relative to 2618, 4032 is a less ductile alloy, making it less forgiving when used with boosted and/or nitrous applications.

The majority of Mahle forged PowerPak kits are made with 4032 alloy and require no additional piston-bore clearance. Mahle pistons are perfectly engineered to allow for the proper clearances assuming normal operation. For example, Mahle pistons for a small block engine will provide proper .0025"-.0030" clearances--right from the box.

2618 is a low-silicon, high-expansion alloy that is used for extreme-duty racing applications such as NASCAR, ALMS, etc. Due to its high-expansion characteristic, this alloy is engineered with additional piston to bore clearance. At the start of a cold engine, the pistons expanding process can be heard and is commonly referred to as the "piston slap". Once the engine warms up the noise subsides as the piston expands to its running clearance. 2618 is a more ductile alloy and grants higher tolerances with higher resistance to detonation. The forgiving characteristics allow for the most extreme conditions, but longevity is eventually negotiated after countless heat cycles.

Mahle pistons are designed for specific applications with the alloy that is best suited for that particular application.  [See table below.]

**Piston Alloy Comparison**

| 4032 | 2618 |
|---|---|
| High silicon | No silicon |
| Low expansion | High expansion |
| Tighter piston-to-wall clearance | More Piston-to-wall clearance needed |
| Quiet Operation | Noise when cold |
| Less ductile | More ductile |
| More stable & consistent | Higher resistance to detonation |
| Longer life cycle | Shorter life cycles |
| Harder | Softer |

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http://www.enginebuildermag.com/Article/45931/piston_options_and_opportunities.aspx

Discussion of cast vs forged pistons and trends in piston manufacture.

**Design Integration/Product Specification**
"When the original equipment manufacturer designs an engine, it develops all of the parts to be integrated into the design," explains Sulprizio. All of the internal components – from cylinder heads to pistons to connecting rods, valves, camshafts and gaskets – are designed to work in harmony to produce the greatest performance, most fuel economy or whatever combination of the two the OEM desires.

"What we do in the aftermarket," says Sulprizio, "is essentially the reverse. We find people changing the rods, valves and heads, literally, everything in the motor. They take what the OE determined worked best and become the engineer themselves. For a piston manufacturer, this requires us to meet a broader set of needs."

Of course, change can be very good for our business and offering a range of products to meet your customers demand is vital. But how do you choose? The question "forged or cast" continues to rage. It's a more complicated question than you might imagine and and the answer depends on each application.

Forged pistons are recognized as the absolute strongest products available, capable of standing up to nearly anything. "Wiseco's motto is 'forgings designed around pistons rather than pistons designed around forgings,'" says Nutter. "We feel this gives the customer the best strength-to-weight ratio at the best price."

Ross' Madsen agrees that aluminum forged pistons are the best material available for mid-to high-power race engines. "I believe 2618 T-61 aluminum is very strong yet pliable and forgiving. In cases of detonation, 2618 is able to flex, give and dissipate heat under the extreme pressure spikes unlike other materials. That's not to say it's bullet-proof but the life expectancy is much higher."

KB's Sulprizio says his company's history (founded in 1922 as United Engine Machine Company by his grandfather) has been in developing and manufacturing cast pistons. "About 6 years ago, we started a forging line, so now we have a variety of products to meet customers' needs, from hypereutectic to forged."

Hypereutectic cast pistons were introduced nearly 20 years ago OEM engines that required something stronger than an ordinary cast piston. Hypereutectic alloys contain a much higher level of silicon than in a typical cast piston alloy, providing additional strength and reduced thermal expansion – in other words, the hypereutectic piston, thanks to its higher silicon content, will expand less when the engine reaches full operating temperature.

“The higher silicon content allows the piston to be machined to a tighter tolerance when cold, explains Federal-Mogul’s Tim Frank. “Because the steel of the cylinder bore typically expands at a different rate than the aluminum of the piston, hypereutectic piston let engine builders fit the bores better.”

F-M’s King says that most pistons used by OEMs today are of the hypereutectic type. “This allows better noise control, and gives advantages in ring designs and fuel emissions standards.”

In the aftermarket, Frank acknowledges the need for precision. “The machining process does need to be more consistent when you’re using a hypereutectic product because you’re starting with a closer piston-to-wall clearance. It can be a little more challenging for a non-sophisticated shop to install hypereutectic pistons, but truthfully, the leading PERs and custom rebuilders recognize the value of hypereutectic and that’s all most will use in their later model engines.”

Sulprizio points out that castings offer significant benefits for people who want low thermal expansion. “It doesn’t have the ductility of the forging, but for people who are really good at managing their motors, it’s a product you can race with tight tolerances.”

The question on everyone’s mind, Sulprizio acknowledges, is “How much horsepower can this piston take?” Because forged pistons have the “strength” label, does that mean hypereutectic are weak?

“I look at it this way: 20 years ago, the OEs couldn’t put out twin-turbos or other exotic engine components and have them effectively managed on the street. Today, however, turbos, small-displacement motors and high horsepower is the norm. The difference? The computer.”

Today’s computer-controlled engines are more carefully and precisely managed, allowing a greater range of performance than ever thought possible. “I try to describe it to people who want to just talk horsepower like this: ‘It’s really what you can manage. I can’t tell you you can’t make 400-500 hp with a hypereutectic piston, because if you can manage the rest of the engine you certainly can,’” says Sulprizio.

“The OEs have improved their management – they’re running cast pistons yet they’re making more high horsepower, high-output, small motors than ever before,” he says. “It’s how well you play the engine management game.”

Because both KB and Federal-Mogul supply forged pistons as well, representatives from both companies take pains to explain that applications for both exist, and that proper selection comes down to recognizing the ultimate requirement of the engine.

“That’s the beauty of our market,” says Sulprizio. “It gives people the chance to work with a variety of parts. Crate motors, for example, take that away, and require builders to work with very carefully specified parts. When people REALLY want to put an engine together, however, they want to have a variety of choices.”
What’s the Buzz?

Even with the surge of nostalgia vehicles and restoration engines, advancements in internal engine components continue to be made. Those changes are certain to affect the piston of the future, in both gas and diesel applications.

“One of the more interesting changes that is just over the horizon will be in piston crown configuration for direct injection, non-auto ignition applications,” says MAHLE’s McFarland. “On a direct injection diesel piston the crown of the piston also acts as the combustion chamber and normally has an easy-to-machine round-shaped bowl. The direct injection, non-auto-ignition engines often have a deflection ridge designed to promote more complete atomization. This ridge in most cases requires 3D milling and a number of variables come in to play when designing the shape (injection timing, duration, PSI, RPM, Boost PSI if applicable). The proper design of a direct injection piston auto-ignition (diesel) or non-auto-ignition is considerably more involved.”

Future designs are made possible thanks to the advent of CNC machining. “Engine builders are demanding extremely tight tolerances and finishes along with a reasonable delivery time,” affirms Ross’ Madsen. “This is only possible with today's high-end CNC machining centers. The days of 'looks good from here' are over. Holding tolerances in the millionths is no 'lip service' – many engine builders have access to very sophisticated metrology equipment and are able to verify tolerance claims."

Diamond's Beaubien explains that the manufacturing process has been streamlined by CNC machining, resulting in a better product. "We are able to do consistent mill-unders on the crown. In the past, whether the piston was cast or forged, if you just left the underside of the crown alone, it would be rough and inconsistently thick. CNC has made it so much easier to make it uniform under the crown, balancing it out, eliminating stress risers without sacrificing structural integrity."

Future piston designs will absolutely feature deck thickness requirements, says Wiseco's Nutter. "Different forging designs have different deck thickness requirements because the structure underneath really serves to support it. The smaller the unsupported area, the thinner it can be."

For a company like Federal-Mogul, which develops pistons for both OE applications and the aftermarket, the development of new designs can be years in advance of their actual production – but that time frame is shortening. "A few years ago, the typical window of development for new products was 5-7 years," explains F-M's Frank. "Now, those dates are 3-5 years out and the OEM is always pushing to reduce development time even further. The shift is definitely toward piston architecture: the piston designs are becoming more 'deliberate,' especially where the surfaces bridge and carry stresses better without adding weight."

Of course, if it's seen first at the OE, eventually it will find its way to the aftermarket. And luckily, the aftermarket continues to be up to the challenge.

"Skirt coatings, offset pins, Nitrided/Napier rings were happening for us from 2002 to 2008 and at this point we consider these features "standard" rather than "trick," says Nutter.

"The change over to direct injection is going to be a hurdle that tuners haven't seen since the early '80s. The VVT systems are a small hurdle for the domestic engine builders – but Honda and BMW builders work with it every day and everyone will have a good understanding of tuning it within 5 years."

Coatings will continue to play an important role in piston design and development. "There are a lot of coatings available and most have some benefit for some applications. The most widely used are anti-friction skirt coatings that reduce frictional drag. MAHLE's Grafal anti-friction skirt coating is also a compressible membrane that has a unique cushioning property that greatly eliminates the metallic contact between the piston skirt and the bore," says McFarland. "Thermal barrier coatings on the crown are becoming popular, but there are a number of different types with different benefits and it is important that the right coating is used for right application."

Federal-Mogul's Scott Gabrielson explains that as performance goes up, the piston tends to run hotter. "Our Thermo-Shield coating on the top crown, top ring groove or both can reduce microwelding between the piston and ring. Certain applications, such as the Ford 4.6L in the Mustang and the old supercharged Buick 3.6L engine are particularly prone to the microwelding condition."

The advancements in coatings have been helpful, Diamond's Beaubien says, because the base materials have stayed the same despite increases in power demands. "It's like a finely tuned piano," he says. "Everything has to work so well together. The wave of the future is narrower rings, narrower radial widths, thinner oil rings that free up friction while reducing radial tension and making more horsepower. Pistons are more structurally sound and a lot lighter. Keeping up with the cylinder head designs will continue to be a challenge."