The main problems with Porsche engines

Who I am and what it is all about?

Hi, I'm Barry Hart (AKA Baz) ed engineer and technical director of UK Porsche specialists Hartech Automotive aiming to share with you our extensive research into the 3 main problems associated with the Porsche M96/7 engines, a couple of minor ones and a very minor one with the 9A1 Gen 2 engines, our product comparisons and the best and most cost effective solutions. It is a long document and if you are unsure if it is going to be worth the effort - you might like to start by checking out my BIO page 163).

SOLVING PROBLEMS

The easiest way to solve a problem comes from first understanding the cause. Usually when the cause is known – solutions are quick to follow.

With experience many engineers can identify a cause quickly and come up with a perfect solution that works first time. However the causes of some problems (especially when they were not anticipated by the manufacturers) prove very difficult to identify and that is when different explanations emerge (that cannot all be right and where sometimes none of them are right) leaving owners in a vacuum not knowing who to turn to. Some unscrupulous specialists may exploit this but most believe in their conclusions – but have just now worked hard enough or long enough to identify the actual cause.

When there are several different potential explanations, the only way to eliminate those that were wrong, is sometimes to try them all and this can be very expensive and time consuming. Very often arrogance (or not wanting to accept they were wrong) gets in the way of getting to the truth and result in arguments between specialists (especially on the Internet) each defending their corner and their reputation.

One place you cannot hide from the truth is in competitive motorsport and it is often the case that successful motor racing engineers more often get to the bottom of a problem either before others or where no one else can, however this is usually not necessarily because they are gifted with more intelligence or knowledge, but because they know from experience that the best way to find the cause is by grafting away and working longer and harder at finding it.

HARTECH'S APPROACH TO THE RELEASE OF THEIR INTELLECTUAL PROPERTY

We have always addressed problems or design ideas in a formal way by preparing and recording the whole process resulting in an internal report that clarifies the journey and is available for other employees to refer to and benefit from in years ahead - all adding to a large resource of relevant developments (that also enhances the future ability of the team and enables them to keep ahead).

These records are not written for general consumption but recognise that a lot of information (often from what the public consider reputable sources) is wrong and misleading and encouraged us to consider making selected reports available to them to help them make better informed decisions.

They are our intellectual property and of course will help our opposition, potentially result in conflict and probably generate some adverse responses from those who the public now recognise got their advice wrong, but overall we feel the benefit to the public is in many cases worth the downside and anyway if it helps others learn and contributes to the better management of Porsche problems and as a result defends their reputation and customer satisfaction - then we feel (perhaps hope) it is probably worthwhile.

In any case we realise that it is only experienced engineers (or well read and researched individuals) that in many cases will understand it all and even if they then don't admit to the quality of our work – at least it may modify their own opinions for the better in the future.

There will of course be those that will disagree and we invite them to offer the public corresponding and comparative reports to support their position – the lack of which may also allow that public to form their own conclusions about the reliability of their own alternatives.

You will probably only benefit from reading it all and we hope you will find it worthwhile.

Why there are two versions?

But while the contents of this report are probably the most accurate and comprehensive available – I still have a problem in communicating what we know to you because the better and more thorough the research the longer and more detailed the explanation will be.

So if I cut to the chase and present a short concise report (or video) like most others do – it will not enable you to work out who or which is reliable or accurate and if I make it long and detailed enough to demonstrate its accuracy it would take a long time to wade through it all. To try and solve this I have provided a short and long version.

Setting the scene

So you are interested in one of more of the 4 main problems afflicting these engines and I guess mainly how to prevent or delay them affecting your car or if you already have a problem, which solution best suits your needs or is most cost effective.

There is indeed a lot of information posted on the Internet from various sources, some of which is consistent, accurate and beneficial and at the other extreme incorrect and/or downright misleading. There are also a lot of different solutions and products – with various claims and expensive promotions – so it must be very hard for most owners to know who and/or what to believe.

We have undertaken extensive analysis, lengthy testing and the outcome for hundreds of private and commercial customers and thousands of components over more than 15 years has been exceptional during which Hartech have become the Elite supplier.

Providing the highest technical quality and specification usually comes very expensive but because we invested in new CNC machinery, special dedicated tooling and programmes, trained staff and an efficient flow production (that is capable of turning out 1 re-manufactured engine/day) we cannot only keep everything under our own control and scheduling but also keep the lid on costs, combining the highest level of customer satisfaction with moderate costs resulting in our superb reputation.

Having established our credentials - I have provided this factual report to try and help you make up your own mind whatever level you start out at - from simply wanting guidance and short answers to wanting to explore the finest details and justifications at a high technical level and compere them to our competitors and form your own conclusions.

There can be quite a lot of disagreements between specialists. This does not always matter if the solutions they offer work reliably and are affordable. A good example of this would be the cracked or "D" chunked cylinders in the early 996 3.4's where because a huge piece of the cylinder has disappeared – there is no material left in that area to fit a dry liner into – so the original casting needs to be completely machined away and it is essential to replace it with a new cylinder - even if the cause of the cracks was disputed. With bore scores this results in 3 options, replacing the whole cylinder, fitting a thinner liner or plating over the damaged scored area - however there are differences in the reliability of these different solutions that still needs to be explored.

On other occasions their differences may be significant. A good example of this is the damage fretting can do to the bearing housing of an Intermediate shaft that can further damage almost any type of new bearing on the market re-fitted into it.

When it comes to the causes of bore scoring differences of opinion could result in false confidence that a particular solution will prevent it when it could be a waste of money. Even when specialists disagree on causes, the specification of their solutions are often similar (like using alloy Nikasil sleeves in preference to iron liners) and the recommendations for warm up procedures and oil change periods can be much the same and therefore valuable.

So rather than directly picking on competitors solutions I have put together all that we have learned (with graphs and pictures) and all that we know about these 4 problems to inform, educate and expel myths and miss-information. I am sure you understand that the more an experienced and highly qualified engineer knows, the more avenues will be considered, tested and researched and therefore it is impossible to be this thorough and also short and sweet and very difficult to pitch the content to be suitable both for those with little or no engine or engineering knowledge and at the other extreme - experienced automotive engineers.

I think you will discover some very interesting facts and explanations that you may not have come across before that will enlighten you about these failures.

I hope I have pitched it right but I think you will gain the most from the contents if you can take your time to read through the whole thing (intro, technical info, short and long versions) from beginning to end in stages over several days. If you do, you will find that some of the main points have been repeated – (to help those that cherry pick sections from missing important points). It does become more detailed as you go through it all to reinforce the accuracy of our conclusions and your understanding of them.

In case some readers only want to pick and choose there is an index at the end (page 179 so you could easily find topics/pictures, return to them and pick up where you left off) and "short" and "long" versions (to try and suit everyone) plus mention of a couple of other minor issues we are asked about – re-grinding Porsche crankshafts undersize and polishing marks in Nikasil bores - at the end.

I hope that after taking on board the content, whatever engineering or technical level you started out at – you will feel more confident to distinguish between the advice and products presented to the public and feel more confident to make the best decisions.

A SHORT OVERVIEW

Having delayed modernisation of designs and manufacturing methods for far too long - in the early 1990's, Porsche had to invest in a much less expensive way to produce the same high performance 6 cylinder engines, to survive - leading to the M96 engine range.

The outcome was so well conceived (incorporating a revolutionary Lokasil cylinder bore system that required a new type of cylinder block layout) that over the next few years Porsche went from being almost bust to become the most profitable sports car manufacturer in the World with engines for the Boxster range (initially 2.5 and later 2.7 and 3.2 litres) that initially really only had one relatively small failing – the Intermediate Shaft bearing (later solved), but had a lot of other high quality features. But some new problems emerged when the same basic engine was gradually stretched to 3.4, 3.6 and 3.8 litres squeezing ever more power out of the original space without increasing the basic size or dimensions of the first smaller engine.

The main problems emerged later (with cylinder cracking and "D" chunking – but only in a relatively small number) but then we understand that new European Health and safety European legislation banned a crucial process for piston coatings (that was regarded as essential for reliable running with Lokasil bores by the cylinder block manufacturers themselves) forcing a change from a piston coating that used to be regarded as essential to run reliably with a hypereutectic cylinder (which Lokasil was claimed to be) pushing limits of reliability of the original 2.5 litre engine design closer to the edge and introducing bore scoring. Despite this enforced change, failure numbers were still quite low and several specialists offered alternative solutions to those offered by Porsche (of a new or reconditioned engine with the same original specification).

Finally, with a strong balance sheet, they were able to invest in new higher specification 9A1 Gen 2 engines that discarded the Lokasil system (and the resulting cylinder block design) in favour of a more traditional Alusil design and other improvements which re-established their reputation for combining exceptional performance and reliability in the Sports car market.

Producing the M96/7 engines for 10 years with those minor faults, it fell to the independent sector to try and find better solutions and advice for owners to avoid them, delay them or improve rebuild options for those that had failed.

With most independents being from a technician background and with limited resources - the outcome had variable success while those in the market competed with each other for business with various claims and promotions leaving the owners unsure what to do for the best. Some promoted cheaper repair options that proved less reliable while others offered reliable but more expensive ones that were difficult to justify.

Because I coincidentally had an education, experience and background solving similar problems for decades beforehand, the shareholders backed my confidence that sufficient numbers would regularly fail - by investing huge sums in creating and staffing an IN HOUSE precision machine shop and strip and rebuild flow production facility that would enable us to combine the best engineering solutions with affordable prices.

When the numbers increased in line with predictions, the set up was already in place able to handle the complicated and multi-disciplined remanufacturing of engines efficiently enough to offer the best combination of quality and value on the market and following huge success in racing and outstanding customer recommendations and independent accolades, Hartech has now established a World Leading reputation.

All that remains now is to try and help owners to assess the virtues and short comings of different advertised products and solutions and to work out which of many technical explanations of faults and solutions have merit and which are misguided – so they can evaluate the alternatives provisions and providers on the market and make informed choices.

That very difficult task is the subject of this document and to try and reach different levels via the short and longer versions in the hope that it conveys some very important issues to as many readers as possible.

The 3 main failures of M96/7 engines

IMS bearing, Cylinder cracking and “D” chunking, Cylinder scoring.

The 1 main failure reported and investigated of 9A1 Gen 2 engines

Cylinder scoring and seizing Gen 2 9A1 engines (and warm up procedure).

Introduction

We at Hartech have more experience of engine design and manufacture and have better ways to address the inherent weaknesses with cost effective reliable solutions that have stood the test of time resulting in a reputation second to none.

We acknowledge that video representation is becoming more popular than written words and photos and while we intend to venture into that area one day we feel that this report is more suited to this traditional medium for now and are concerned that the content of some of the highly regarded videos we have seen is inaccurate and misleading.

Why there are so many different explanations.

Manufacturers cannot respond quickly enough to emerging longer term weaknesses in designs until the next major model change and often try and avoid responsibility to protect their reputation and against litigation.

Independent repairers who are not absolutely sure which factors or components may be contributing to these failures may insist on unnecessary new replacements - to cover themselves against expensive claims or increase profitability.

Different specialists may come up with different solutions to the same problem – some of which may be equally valid while of the various choices others will emerge as the best, resulting in a choice often relating cost to quality and resulting in premature second rebuilds where some cheaper options fail again.

UNDERSTANDING ISSUES DISCUSSED IN THE LONG VERSIONS.

Even if you are a qualified engineer I still recommend that you speed read the short version before moving on to the more technical longer version – especially the "basic's" section which has been simplified to broaden knowledge.

THE BASICS

There are 8 main technical causes behind these 4 (and most other) problems. (a) Wear (and running in).

(b) Lubrication.
(c) Load/area.
(d) Temperatures.
(e) Fatigue.
(f) Strength of materials (and associated issue relating to cylinder tubes).
(g) Age related stress relieving and warm up procedures.
(h) Catastrophe theory.

(a) Wear takes place in all running machinery when minute pieces of the base material between rubbing surfaces becomes free and disappear in the lubricating oil and are eventually trapped by the oil filter.

A considerable amount of research has been conducted into the type of wear that hypereutectic alloy cylinders experience (Alusil), most or all of which has been associated with the new Lokasil cylinder bores in M96/7 engines on the assumption it is the same. Our research uniquely questions this connection and concludes that there are differences that need taking into account when understanding failures.

(b) Lubrication. Lubrication is supposed to keep the 2 metal running surfaces apart from each other as a result of the existence of an oil film which can be hydrostatic (pumped in under pressure), hydrodynamic (where the movement of surfaces near each other creates a wave effect that generates a pressure front) or boundary lubrication where metal to metal is in contact. It can also be a combination of some or all in different circumstances.

(c) **Load/area** The same load, weight or force applied over a smaller area increases the load/unit area and causes more damage and penetration as a result. All lubricated bearing surfaces rely upon the load being spread over sufficiently large an area not to penetrate the oil film. Too much load or too small an area for the load and boundary lubrication conditions are in effect.

(d) **Temperatures.** The raised temperatures of 2 adjacent wear faces/parts both alters the clearances between them (as differential expansion occurs) and also influences the viscosity of the oil between them and any oil pressure present and results in thinner oil films and component faces being closer to touching under high loads.

(e) **Fatigue.** Metals can withstand weights loads and forces and return to the same shape many thousands of times without a problem unless those weights, loads or forces exceed a pre-determined amount after which they cause a small crack to appear on the outer surface (because it is stretched the most) that grows larger until the remaining area taking the same load is too small and a fracture results.

(f) **Strength of materials.**

Stiffness (or resistance to deformation) is often more important that tensile strength and tubes are not naturally stiff so because the cylinder design of the M96/7 engines has an open tube (open deck) top and bottom, it allows the cylinders to deform under load and go oval, eventually fatiguing and cracking.

Hartech replacement Aerospace alloy Nikasil plated wet cylinders are probably the only ones on the market that close the deck maintaining the roundness and security of the cylinder for added reliability.

(g) Age related stress relieving and warm up procedures.

Parts where the original material was subjected to high manufacturing temperatures (metals and castings) will experience variable cooling (as the outside always cools first while the inside is still hot and expanded. This results in trapped internal stresses that can be released every time the part subsequently experiences a heat/cool cycle allowing it to slightly change shape and resulting in some clearances becoming larger or tighter with age (the latter moving closer to a cold clearance that causes damage until the parts are fully warmed up).

(h) Catastrophe theory.

Some components will work just as well when they approach their critical failure point as when they are a long way from it - but then – the smallest of changes can result in complete and total failure afflicting many other parts and often making predictions about failure issues and comparisons between different examples difficult to quantify.

HOW THE ABOVE CAUSES INFLUENCE RELIABILITY

(1) **IMS bearing.**

The original bearing was just too small to be totally reliable in all circumstances and tolerance fits and numerous different ball and roller bearing replacements the same size are little or no better (except a plain oil pressure fed bearing which is expensive). As mileages increase – if the original bearing has survived it might be better to leave it alone than try and replace it because fitting replacements without stripping the engine requires special skills and tools and can cause more problems.

The later and larger Porsche replacement bearing is extremely reliable especially with the seal removed (but can only be fitted to engines if they are stripped and then only to later type camshaft chain drive examples).

Hartech re-manufacture both types of IMS to fit the larger bearing to any early or later version during a rebuild.

(2) **Cylinder cracking and "D" chunking**.

The original engine design for a 2.5 litre 6*cylinder engine had thick enough cylinders to remain stable. By increasing the bore size by between 40% and 52% (3.4 to 3.8) without altering the spaces between the cylinders and block - the coolant space between them became smaller and because the top and bottom of the cylinders was free standing and unsupported (called "open deck") - eventually the higher loads from the bigger engines were too much for some of the thinner cylinders that cracked or broke away in "D" shaped chunks.

Hartech machine away all of the original cylinder and fit an aerospace alloy Nikasil plated closed deck wet liner alternative (with extra cooling ribs to compensate for the reduced cooling capacity) that also converts it to a closed deck similar to the Original Porsche GT3 and Turbo cylinders all of which are ultra-reliable.

Although the cost of this process is discounted if all 6 cylinders are replaced Hartech can also strengthen the undamaged remaining Lokasil cylinders to prevent cracking as a less expensive (but also less permanent) option.

(3) **Cylinder scoring M96/7 3.4, 3.6 and 3.8 engines.**

This is an unusual failure in the industry but quite common in some M96/7 engine types - the cause of which has confused many and resulted in a lot of misinformation. This was primarily because the cylinder block castings and the piston coatings in some later models were different to earlier models while the new Lokasil cylinder system was claimed to work the same as another successful bore solution called Alusil. These and various other changes made it difficult to identify the primary cause or causes with several different explanations resulting, some of which were wrong, some close to being right (but missing important contributory factors), and some (like ours) spot on resulting in some good and some misleading advice and recommendations.

The first Boxster 2.5, 2.7, 3.2 and most of the 996 3.4 engines had a new type of cast in cylinder referred to by the manufacturers (and most specialists) as a "hypereutectic cylinder" called Lokasil with hard silicon particles dispersed in an aluminium alloy. Although it was manufactured differently, it was claimed to work the same as the previously successful Alusil hypereutectic cylinders used in the 924S, 944 and 968 models, however the way the silicon particles were entrapped in the alloy was different (and not strictly hypereutectic) adding confusion to analysing the results.

The previous Alusil and these Lokasil bore engines worked well with hard iron coated pistons but new Health and Safety European legislation prevented the hard iron coating on the earlier pistons (that did not score bores) from being used on later pistons (that did). The new coating proved to be insufficiently hard and/or well bonded to the piston face to resist the wear caused by hard silicon particles in the cylinder wall matrix for as long as the original iron coated ones did.

The combination of relatively large silicon particles that can break free and jam between the piston and the cylinder wall resulted in Lokasil proving less reliable when running with a softer plastic coated piston than Alusil with a harder coating and differences in the running temperature and dry start-up lubrication combined to result in bank 2 suffering failures at about half the typical mileages of bank 1 cylinders.
The slightly less expensive solution of fitting dry iron liners has not proven as reliable because with the original alloy cylinder being so weak enough to eventually became oval, machining it even thinner (to fit the liner) meant it was even less able to resist movement resulting in liners often becoming loose and/or dropping down the bore while the extra running clearance needed (due to the different thermal expansion rates) had resulted in most manufacturers abandoning that solution decades before in favour of alloy bores.

Although fitting a thin Nikasil plated alloy dry liner solves the thermal expansion and running clearance issues of an iron liner, 2 tubes inside each other are not as stiff as one tube of the same overall dimensions and usually leaves the top open deck free to flex. For these reasons the Hartech replacement cylinder was designed as a complete new cylinder, which is stiffer, includes a ribbed outside surface area (to increase cooling rates) – and without an interface (where 2 tubes reduces thermal conduction), keeps the piston and oil film cooler. It is therefore technically a better solution than either a ferrous liner – or a thin dry Nikasil plated alloy liner.

(4) **Cylinder scoring and seizing Gen 2 9A1 engines**.

By reverting to a technically superior closed deck construction (and a new harder piston coating) the cylinders became stiffer and better supported and the piston coatings lasted longer (resulting in superb reliability and high mileages without failures). However this left a very small number vulnerable when after many thousands of heat, cool and thermal expansion and contraction cycles - the lower cylinder area in a few examples slightly contracted squeezing the cylinder bore smaller and closer to the piston, reducing the clearances until on premature fast warm ups the piston expanded before the lower cylinder and could cause cold seizures.

THE LONG DETAILED TECHNICAL VERSION

The 3 main failures of M96/7 engines

(1) IMS bearing.
(2) Cylinder cracking and “D” chunking.
(3) Cylinder scoring.

The 1 main failure reported and investigated of 9A1 Gen 2 engines.

(4) Cylinder scoring and seizing Gen 2 9A1 engines (and warm up procedure).

History

Early in the new millennium (around 2002) we started investigating various problems as they materialised. The causes were quick to establish for the first 2 (IMS bearing failure and “D” chunking and cylinder cracking) but much longer for the 3rd (cylinder scoring) and very quick once again for the 4th one (Gen 2 9A1 seizing) but after they were all established and proven – the causes were simple to understand and explain in all cases but only when the reasons were directed towards engineers with a lot of experience and a broad knowledge base.

Well over 15 years ago we wrote thousands of words and pages of text, photos and drawings for our own buyers guide (web site) and warned readers against some options we thought would prove unreliable, posted answers and photos on the Internet – to try and explain things - but still the same old questions keep getting asked years later and explanations differ from experts. Meanwhile we have received engines rebuilt elsewhere that have failed for a 2nd time, seen evidence of the very failures that we warned about, learned more, improved some designs, introduced new products (that we need to update information on) and the market has more choices. All of this leaves owners unsure what to do and who to believe.

Internet Video reproductions seem popular, industry leading and some are very well presented and no doubt provide a great service to those unfamiliar with the internals and many of the issues. Indeed - now that reading long technical reports is no longer as attractive we accept that we need to move with the times and try in future to explain what we have found out, know and supply some information - via video's – where appropriate.

However there is also a lot of mis-information and irrelevant content in some videos we watch on the Internet which can also miss-inform. So while we fully accept that Video presentations can be very easy to watch and seem convincing (and we applaud the creators of those that are very good indeed and entertaining as well) – many contain advice and conclusions we disagree with and/or omit the actual causes the titles claim to reveal.

It is easier to sit back and simply watch someone talking to you with physical hands on examples than to concentrating on reading - but it is also easier to become mesmerised and you have to be careful that a lot of familiar points and interesting visuals do not diminish your resolve to pick out and concentrate on those issues that the video is supposed to be about. So with Video presentations it is especially important to be able to distinguish between what is actually and factually correct and what is nonsense portrayed in a convincing way once the viewer is captivated.

I am going to try and avoid adding to the existing bad feeling between specialists trying to do their best and the arguments resulting by avoiding identifying them by name or implication - but I hope that by the time you have finished absorbing the contents of this report – you will be able to work out which explanations are more likely to be right - for yourselves. I still think it is going to be very difficult to convey all the results of our own investigations into these failures via video since I think readers/viewers would need to take in the contents in stages and that it would often be preferable to be able to refer back to connected issues easily and I think this is still best performed in report format like this.

This report is therefore probably not going to be our last written one but it is going to try and finally bottom the issues with all 4 common failures specifically aimed at those people who like reading words (or seeing drawings or pictures).

To achieve the greatest benefit from it we suggest you first check out some simple basics about automotive engineering – that have an influence on the outcome - or you may get lost in the subsequent content – so please – whatever you decide to skip through or ignore – try and read those initial basics that apply to almost every engineering problem and from which most answers flow.

Why there are different explanations.

Some faults can only be tested for over many years and thousands of miles making it impossible for manufacturers to test for all eventualities in advance, especially if they are contributed to by repeated natural heat cool cycles and high mileages. Afterwards it is often too late to change anything and concerns over liability muddy the waters and frequently leave the independent sector to come up with solutions from much more limited resources and fewer statistics upon which to base correlations on.

Their success (or failure) often relates to the level of their experience, their technical knowledge base, the repeated numbers they observe and the results of theirs (and others) solutions in the market place.

By simple mathematics if a business made say 5% profit on an engine rebuild, then if they get something wrong and just one rebuild later fails – the warranty costs would require at least another 20 engines to be rebuilt successfully just to recover the loss and break even. Even more successful rebuilds would be required to enable them to re-invest and survive, so potentially weeks of work would be needed to make up for one simple mistake, all because they tried to find a better way to help their customers over a fault that was not theirs in the first place. This means that after all their design, test and re-manufacturing work to help their customers – they still would pay heavily for any mistake.

Another important consideration for owners is the issue of warranties or guarantees. If one business supplies only a part of the repair and other work is carried out by the specialist or the owner – who carries the financial responsibility if it fails. Most suppliers limit their responsibility to the cost of the part or service they supplied and in the case of say fitting a liner or supplying a special bearing etc – if it failed a whole complete rebuild would be needed at huge cost which such suppliers (even if they accepted liability) would be unlikely to pay out. It is therefore very important for owners to only deal with people and products that have a superb long established reputation for success and being ethical and honourable if a problem emerges.

So if some specialists are not absolutely sure about the influence of some technical issues on the failures, you can understand why they may insist on sending the parts needing repair to trusted sources or replacing some parts that were not strictly necessary (even if those parts had nothing to do with the primary cause). This can lead to some engine remanufacturers insisting on changing some parts that others are happy to re-fit and trying to justify it with explanations connecting the need to the original failure, that others disagree with.

On the other hand some unscrupulous suppliers may not care about the long term satisfaction because they would not intend to do anything about it anyway if their product or service subsequently failed. The market is therefore full of specialists that sometimes fit sub-standard solutions and re-fit vulnerable parts and others that fit expensive solutions and unnecessary additional replacements and many more that simply make it impossible to obtain fair treatment if something goes wrong. The more highly qualified and familiar the team are with engine related re-design and repair, the more testing they undertake, the more experienced the team, the more comprehensive their equipment and the greater number of engines they see and repair – the less likely the outcome is to be unreliable or unnecessarily expensive. In contrast the less qualified and experienced the team are at engine failure re-design and the more they have to sub-contract out, the less testing and repairs they undertake - the less likely their rebuilds will be reliable and the more complaints that will emerge – so Reputation is therefore vital.

However - It is not always necessary to understand the cause of a failure in order to come up with a good solution and sometimes there is more than one solution that will work perfectly well where reputation and feedback can help rank the outcome.

UNDERSTANDING ISSUES DISCUSSED.

If you are a qualified general engineer you should be able to follow the extensive research successfully but if you do not have engine building experience and/or are not familiar with the parts and processes then you might get bogged down when reading this longer versions unless you first read the very basic descriptions of the main technical knowledge base needed that enables most experienced engineers to follow and concentrate on the issues raised.

To help we have provided a brief description of those key basics.

THE BASICS

There are 8 main technical causes behind these 4 problems.

(a) Wear (and running in).
(b) Lubrication.
(c) Load/area.
(d) Temperatures.
(e) Fatigue. S
(f) Strength of materials (and associated issue relating to cylinder tubes).
(g) Age related stress relieving and warm up procedures.
(h) Catastrophe theory.

(a) Wear

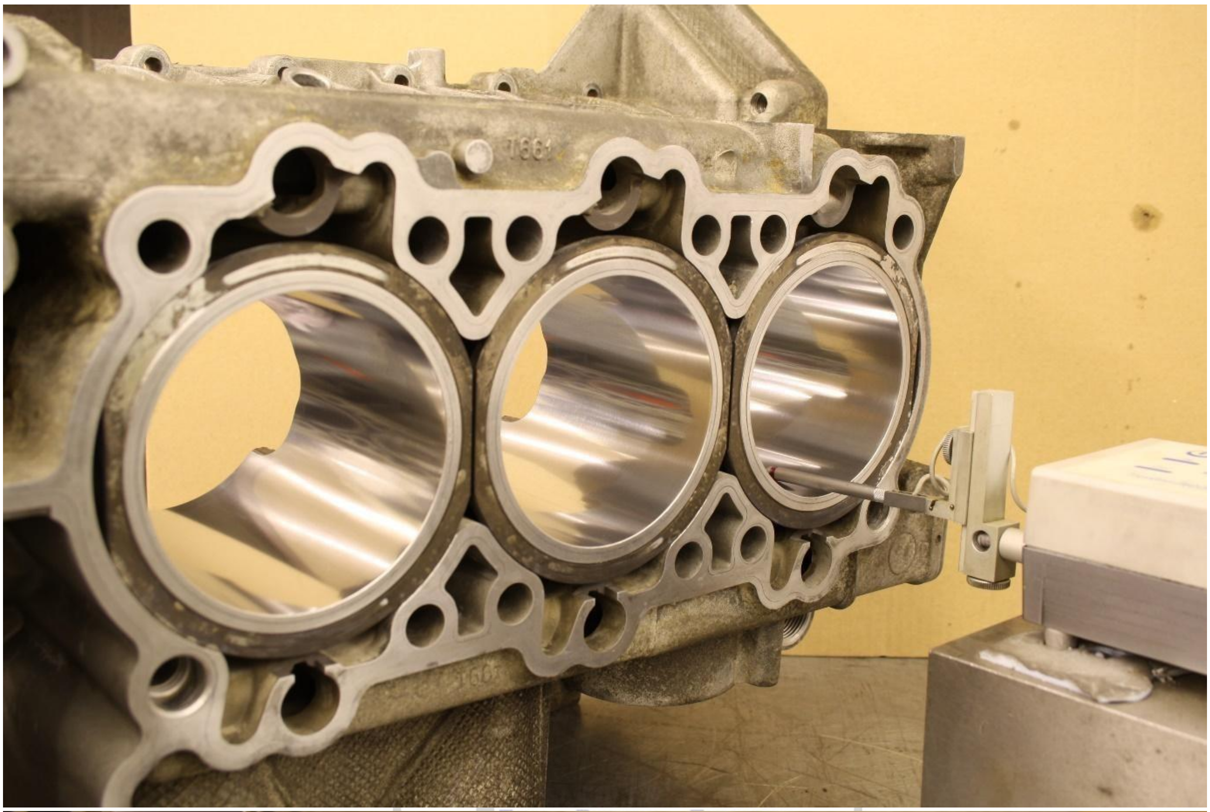
When the parts are manufactured, they may look smooth but they are all microscopically rough at the surfaces and the rougher they are the cheaper they are to produce. The type of material can influence how quickly these minute particles wear off and how big they are.

"RUNNING IN" is a procedure to allow the peaks of the roughness in each mating part to be rubbed off quickly so that the mating surfaces become smoother (which then spreads the load over a greater area reducing its impact).

If this "running in procedure" is done with the mating surfaces running too fast or with too much force between them then the peaks get torn more than they are rubbed smoother and the result will not last as long – hence the usual advice for running in a new engine or gearbox at moderate loads and mid-range revs for a period. This applies to both rotating and reciprocating engine parts.

For example - when a cylinder bore is created it is better to have some roughness in the microscopic surface finish that can be measured by machinery and the same applies to piston rings edges that are better to be quite sharp than chamfered. Even the angles, depth and displacement of honing has ideal configurations and is specified with ideal dimensions and quality control limits.

Pictures of one of our cylinders having the surface finish checked follow.



The initial wear resulting from "running in" helps smooth any rough edges that are initially taking all the contact and once it is done the loads are spread over a wider area and impact less into the surface. Carried out correctly running in extends the life of critical engine parts.

Wear in Hypereutectic cylinders.

It is essential to understand that the Alusil cylinder system (used in earlier Porsche engines) has been the subject of much previous International research but the newer M96/7 **Lokasil cylinder system** has not. Because both have been described by the manufacturer as Hypereutectic cylinders (and that although they were made differently were claimed to work effectively in the same way in practice) the results of that previous Alusil research have understandably been applied by many to Lokasil. But we eventually worked out that there are significant differences between them and therefore think this was misleading and certainly delayed us identifying the actual failure causes.

It might be worth you looking up Hyper (and hypo) eutectic alloys on the Internet to understand the phase differences in cooling during manufacture. Briefly - a true Hypereutectic alloy (like Alusil) is molten aluminium with too much silicon in it to be absorbed into the alloy which on cooling allows the excess to form small hard silicon nodules evenly distributed and well bonded throughout the matrix. The aluminium is then slightly etched or exposed back from the surface leaving space for oil retention and creates a light hard wearing cylinder surface that expands and contracts more like the piston allowing tighter clearances, longer life and low oil consumption. However - for long life - the aluminium pistons used have to have an electroplated hard iron skin and this combination will typically last for several hundred thousand miles.

Eventually wear loosens some of the silicon particles which reduces the proportion of silicon nodules near the surface, reduces space for oil retention and allows the remaining aluminium to tear and score or seize.

Alusil combined with hard coated pistons has proven long lasting and perhaps the only downside is that the silicon is present all over the cylinder block casting making it hard and very expensive to machine (although strong and long lasting once it has been).

However although it is described as being the same in practice - Lokasil is not manufactured the same way. An analogy for it might be that It ends up more like a tarmacadam road (with stones mixed in with tar) or concrete (with stones mixed in cement) because the silicon content does not grow out of the molten solution but by molten aluminium flowing into a porous tube in which the silicon particles have already been suspended.

This would be similar to stones being glued to a net and held apart in a mould and then flowing tarmac or cement into the mould that flows around the stones and in the process melts the net so it ends up as it sets round the stones in a matrix similarly distributed as with Alusil but with silicon particles already full size suspended within it and not growing from within it as the molten matrix cools.

Lokasil has small particles of silicon suspended in a binding agent forming something similar to a liner which is “cast in” with molten aluminium flowing under huge pressure into the spaces burning off the binder and solidifying around the silicon (and this is not in our opinion the same as a true hypereutectic process). As a result our research shows us that the silicon is less evenly distributed than in Alusil, the is bonding is less secure and the resulting alloy is stiff but weaker.

The benefit with Lokasil came when machining the whole crankcase because the hard silicon parts are only located where the cylinder and piston run (hence the description **LOCA**l **SIL**icon) allowing the remaining cylinder block to be machined more quickly and cheaply – a brilliant idea.

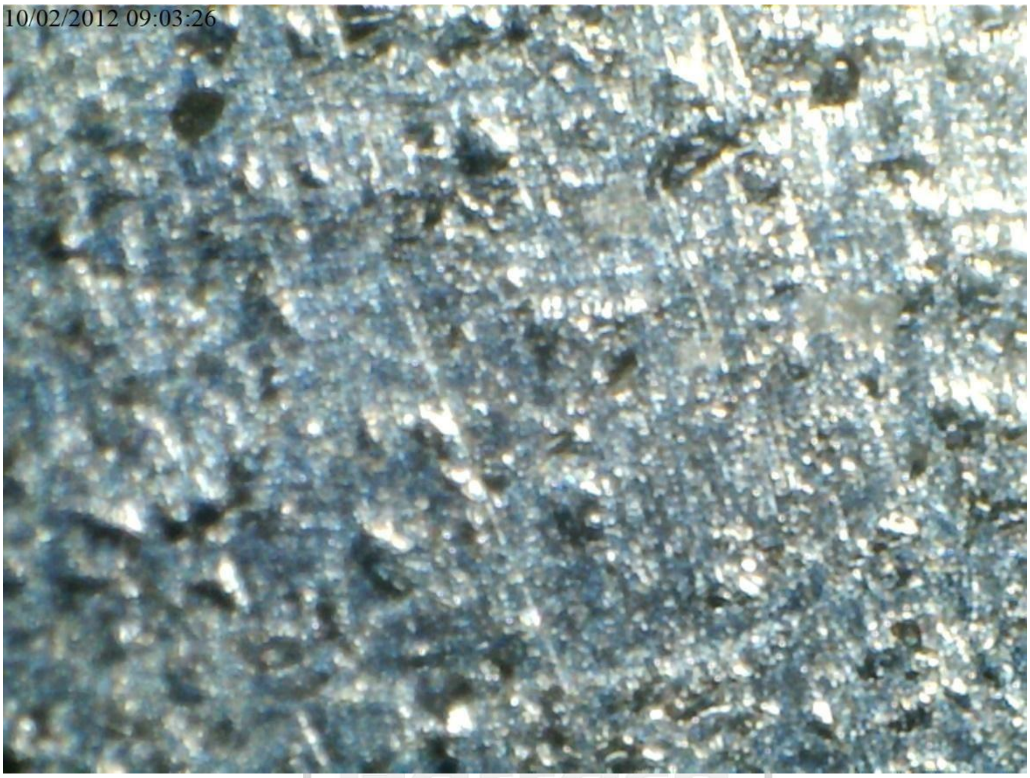
Similar to Alusil it also requires a hard coated piston to survive (and perhaps more so).

When Lokasil wears it has 2 different wear patterns. The lower mileage pattern is when uneven silicon distribution or poor bonding results in some of the silicon particles eventually becoming loose from the surface to float entrapped between the piston and cylinder bore. This places the piston thrust load directly onto a minute piece of silicon (instead of being spread across the whole surface of the piston face) and the increased load/unit area penetrates the oil film and the hard silicon particles rub up and down the bore until they either get stuck on the piston face, loosen more particles, are washed away with the oil or damage the piston, cylinder bore or both. The harder the piston coating the longer they will last.

A Lokasil bore that has well bonded and evenly distributed silicon particles running with hard iron coated pistons may last 150K miles or more and eventually only fail in a similar mode to Alusil.

Lokasil does have some similarities with a hypereutectic Alusil cylinder as they both contain relatively soft aluminium and very hard silicon particles. When honed smooth they then undergo a process of exposing the aluminium back microscopically so that the result is a mixture of peaks of hard silicon and soft aluminium set at a slightly lower level below the surface that creates space for oil retention and ensures that the pistons and rings run with an oil film between the piston, rings and hard silicon part of the cylinder bores (the amount the silicon particles are supposed to stick up above the aluminium is about 1/1000mm or 0.00004”).

This is a picture using a special microscope camera showing how the surface is composed, the aluminium and the small pieces of silicon.



The honing process will flatten the surface of the silicon particles (so some are retained in the aluminium deeper than others depending on their position and size in the matrix when they were honed) and creates oil retention spaces at ideal angles to help prolong the life of the rings.

Piston rings bang into the silicon particles as they pass by and the oil being washed and pressured into each cavity on every stroke very slowly erodes the aluminium such that eventually some silicon particles become loose and are released from the surface as wear particles. The rate of release will be slow to start with (because any large silicon particles will have been removed by the honing and exposing process) so the next to be released will be small particles (because they are retained on flanks that are not dovetailed into the aluminium matrix but incorporate angles that will release them and are only retained by the bond between them and the aluminium).

Eventually aluminium oil washed erosion and ring contact will release bigger particles that may then wear the aluminium they come into contact with more quickly and impact on other particles nearby and knock them loose as well increasing the release rate and size. This results is a gradual increase in the number of silicon particles released and their size while at the same time the surface presented to the rings and piston face becomes flatter and with an increased aluminium proportion (which is soft). However the thickness of the silicon rich area is sufficient to always expose more silicon to the bore but not as exposed as when first created.

Over time the increased silicon particle release, damages the piston face (the rate of which depends on the type, suitability and durability of the piston coating) while the surfaces in the heavy wear areas (of maximum piston loads) has less "bumps" which reduces the spaces for oil to be retained in and eventually the two surfaces micro-weld from friction and result in deep scores to the piston and cylinder surface.

(b) Lubrication.

Lubrication is supposed to keep the 2 metal running surfaces apart from each other as a result of the existence of an oil film and can be listed as hydrostatic, hydrodynamic or boundary lubrication (or a combination in different circumstances).

Hydrostatic is when there is an oil pressure supply and as long as the oil pressure is high enough to keep the loaded parts separate from each other there should only ever be very minor wear rates. This would be typical of crankshaft and/or camshaft bearing locations when an engine is running and oil pressure is sufficient to overcome the loads and keep the metal parts separated. Neither standard IMS bearing failure nor bore scoring enjoy a pressurised oil supply.

Hydrodynamic is when the motion of the parts moves the oil film and generates a wave or entraps oil - that creates its own pressure between them due to the motion between the 2 mating parts. This is more typical of the balls in a ball bearing rolling against grease or oil (as they revolve in the ball track) and the shear forces and friction forming a wave front on the leading edge of the balls as they rotate creating a pressure point.

It also occurs with a piston and rings in a cylinder bore where the oil is splash delivered to the cylinder bore as it ascends until the piston is at the higher level in the bore and slides in between the piston and the bore as it descends when the same shear forces and friction between them create a small pressure front. The rings then force the oil downwards with the piston creating a hydrodynamic oil pressure between the piston and the cylinder bore.

Boundary

This is when there is no oil pressure or oil film thickness (or it is too small to resist the loads applied) resulting in metal to metal contact. This would frequently be on start-up and/or when loads or speeds are high and/or viscosity is low. These conditions would be met on start up in rotating bearings or sliding faces (so crank and camshafts and pistons and cylinder bores when starting the engine particularly after a long period without use).

A new car's IMS bearing should contain grease all over the balls and tracks when stationary (due to its high viscosity) and therefore should not have boundary lubrication problems on re-start but could do if the grease has washed out of the shield before the oil splash can enter the bearing on start-up.

Because the M96/7 layout has horizontal pistons and cylinders – when it is switched off - gravity will settle the piston at the bottom of the cylinder with most of the clearance at the top. The hot oil between the piston and the cylinder wall will then drip downwards and collect at the bottom of each cylinder creating an oil rich surface at the bottom on next start-up and a reduced oil film (or even dry area) at the top until splash oil (or oil delivered from the spray jets) lubricates the cylinder bores again. Because the piston is oval and the biggest diameter is at the top and bottom, the sides of the piston have more clearance so the oil will easily drip away from the top and down the sides of the pistons towards the bottom when hot and on shut down – especially as some heat soak when the engine it stopped increases the temperature on the piston face for a short while.

As long as there is some oil remaining between the surfaces when left static and as long as the speed and loads are low on re-start -then hydrodynamic oil pressure can be established quickly enough to prevent boundary conditions of metal to metal contact between the piston and the cylinder wall by the time splash oil reverts the lubrication to running conditions and hydrodynamic lubrication is re-established. To avoid boundary conditions some large engines have an oil pressure delivery system that operates before rotating any of the internal parts. In our experience stripping down long-standing engines - some synthetic oils drip off surfaces when hot and leaves them relatively dry for the next start-up while others that are thicker to start with (or contain suitable additives) and retain an oil film for longer, which is beneficial.

(c) **Load/area** A load (or force) applied to an area results in a unit load or force/area. So if the load increases or the area reduces the unit load is higher (hence a stiletto heel may puncture lino where a normal larger heel would not under the same weight). In terms of how this affects lubrication – if a load is present between 2 mating parts with an oil film in between them then it will try and gradually squeeze the oil out. How well the oil film keeps them apart depends partly upon the oil pressure, the load applied to the area with the oil film entrapped, partly on how long the load is applied for and partly and how quickly the oil that is squeezed out is replaced. The rate that it is squeezed out also increases if the clearance is bigger or the viscosity of the oil is lower.

In relation to pistons and cylinder bores, because there is no oil pressure feed - entrapped oil is squeezed out during each cylinder descending power stroke and the resulting oil film thickness is therefore reduced under load.

The higher the pressure (bigger the throttle is opened) the quicker the oil film will reduce in thickness and the longer period it is applied over the thinner the oil film will become. So because the load or force is applied 3 times longer/stroke at say 2000 rpm than it is at 6000 rpm - high loads at low revs will create the worst scenario and result in the thinnest oil film separating the piston face from the cylinder wall whereas at peak revs there is less time to squeeze out the oil film while the sheer increased speed and inertia of the piston avoid it digging into the cylinder surface.

If a piece of silicon (or other debris) becomes trapped between the piston and the cylinder wall then all the thrust load driving the car is placed on the minute area of the debris that then easily overcomes the oil film strength and tears into the running surfaces.

(d) **Temperatures.** The raised temperatures of 2 adjacent wear faces/parts both alters the clearances between them (as differential expansion occurs) and also influences the viscosity of the oil between them and any oil pressure present and results in thinner oil films and component faces being closer to touching under high loads.

(e) **Fatigue.** When metal parts are subjected to loads or forces they will bend, compress or stretch. If they do so beyond their yield point they will permanently deform. If they bend within their elastic limit this can still result in minute surface cracks appearing (because the outside of the material in bending is stretched further than the inside and may exceed the yield point just at the extremities) so although the elastic limit or yield point may not be exceeded internally – it may be at the outside resulting in surface cracks appearing there. As these cracks gradually enlarge the remaining cross-sectional area of the material gets smaller – so the load/unit area increases and sustains the process until the area left is smaller than the ultimate tensile stress and it breaks. Generally steels can be designed such that as long as no cracks appear (because the external surfaces never stretch enough to exceed their yield point) - they can withstand an infinite number of these stress reversals and never fail. Aluminium alloys however always have a number of stress reversals at which they will initiate a crack and eventually fail.

Strength of materials.

Most people imagine that the tensile strength (resistance to pulling apart) of a material is its most important quality but actually it is the stiffness (resistance to flexing under load) that is often more relevant to engine reliability.

If you calculate the stiffness potential of different shapes from 2nd moment of areas (or moment of inertia calculations), tubes seem quite good because they use the radius to the 4th power in the calculations making a hollow tube of the same weight as a solid one, bigger in the outside diameter and therefore theoretically much stiffer, whereas calculations for rectangular shapes use the 3rd power of the width and depth. But rectangular tubes are usually specified for loads in one direction whereas tubes (being round) have the same stiffness in any direction. This can lead to a misunderstanding that hollow circular tubes are as good as rectangular tubes or “I” beam shapes in single direction loading – which they are not.

If we ignore those calculations I think there is a simpler way to understand why structures that require stiffness from loads applied in a single direction - are best designed like an “I” beam or rectangular tube. It is because as long as the central or side vertical components do not buckle - they keep the top and bottom sections (which are usually thicker) the same distance apart in bending and this in turn changes the bending forces into tension and compression of the top and bottom layers – which metals are generally good at resisting).

Although tubes provide a good way to provide a relatively stiff shape if the loads applied are in all and any random direction, they are not as stiff in bending in any one direction as an “I” or box section tube - because there is no straight component keeping the top and bottom parts of the tube the same distance apart. Instead, the curved cross sections allow the top and bottom layers to freely move closer together (in bending) and the sides bow outwards (as the tube goes oval) and therefore rely more on the resistance to bending of the thin unsupported sections. They are therefore best used for flexible designs like fishing rods and flag poles or where for practical reasons they need to be bent in different planes subjected to torsional loads (like in motorcycle frames).

Cylinder tubes in cylinder blocks need to be stiff to resist the forces applied in just one direction by the pistons pushing against one side (to turn the crankshaft via the connecting rods) and so are usually thick and/or joined at the top (and sometimes the bottom) to the external casting block to make them stiff. Returning to the theory, the additional support of the exterior block is then at a greater distance from the centre, exploiting the benefits from the 2nd moment of area calculations - and this is called a "closed deck design".

The 924S, 944 and 968 Porsche cylinder blocks were cast-In "open deck" tubes (with the top of the cylinder an unrestrained free standing tube) but the material in use was ALUSIL which is much stiffer and stronger than plain aluminium alloy (or a combination of alloy and Lokasil) and the distortion at the top of the cylinders was minimal (often noticed by small areas of rubbing or fretting where the head gasket fitted). Only highly tuned non-standard turbo versions were ever powerful enough to gradually create a problem with the flexing of the cylinder tubes - leading to cracks.

M96/7 (non GT3 or turbo engines) have an open deck tubular cylinder design at the top and bottom and because most of the cylinder section is weaker soft aluminium (and only the centre section is the harder hypereutectic mixture of aluminium and silicon) they do flex.

To maintain a good head gasket seal and prevent small flexing movements between the top of the cylinder face and the head gasket damaging the sealing face a thin plastic coating was bonded top and bottom – and that and the top and bottom layer of the gasket had a circular segment on the front and rear pressure face cut out – so the gasket face could move with the flexing cylinder and not damage the thin plastic seal. In this picture the centre of the 3 layer metal gasket is the light colour positioned in the thrust direction and reveals the area removed from the top and bottom layer to allow it to flex.

(f) Age related stress relieving and warm up procedures.

When parts are cast or forged (or manufactured with any significant heat process) the rate of cooling influences the final size and retained stresses inside the material. This is particularly relevant in castings where the parent metal has to be molten to flow into the mould shapes.

What happens is that the outside of any shape cools first and freezes solid before the inside - which is still hot and therefore still expanded. As the inside slowly cools the already solid and cooled outside prevents the inside areas from fully pulling the outside inwards and leaves a stress inside the material pulling inwards towards the centre.

Because of this they used to leave large castings for machinery (like lathes and mills etc) outside to “weather” for several years to help these stresses equalise but this was only actually allowing the material to go through heat and cool cycles every day (when they didn’t have large enough ovens to fit them in and/or couldn't afford the cost, space or time delay. So they simply cast more than they needed and left some of them outside to call off when required after multiple daily and seasonal thermal cycles. The process can be speeded up by heating and cooling in shorter or more controlled cycles more suitable for the material in question.

Also - when material is machined it removes the outer skin and this relieves the stress that was present trying to resist pulling it inwards towards the centre and distorts the material so it is a slightly different shape than it was before and during machining. To counter this some components are often roughed out first and then either finally machined to finished size (after it was considered it had stress relieved enough) or heat treated again before final machining to get more of the stress out.

Very few quantity mass produced castings can benefit from this as time and costs do not allow it so many cast engine cases and cylinder blocks are not stress relieved as a result.

Many engine builders know this since when they remove a cylinder head the surface is often distorted because of the heat/cool cycles every time the engine was started, run and then switched off again - and as a result the parts need remachining before they can rely on them fitting back and sealing the head gasket.

A classic example is the crankcase of a 944/968 which incorporates a crank carrier lower casting in front of which there is a split joint where the oil pump seals. Although the bolts hold them together during their life – if you remove the bolts and casting to replace the main bearings the lower half springs to a different shape and size than it was before and sticks out from the upper block by up to half a mm and unless that is dealt with - the oil pump then often does not seal properly on the now stepped sealing face that should be flat.

So every thermal cycle results in some atomic level movement in most castings and the bigger the section areas, volumes and differences, the more it affects the overall shape and size.

The studs and bolts that tighten on joined parts often also distorts them and so sometimes a false part (like a cylinder head plate) may be fitted and torqued up before a final cylinder bore is sized to make sure it is round after the bolts from the real head are tightened on assembly.

These affects can very slightly alter round holes to very slightly oval, shrink them or expand them or make flat surfaces bowed and usually if it is the result of the original internal casting stresses – it can take a huge number of thermal cycles to move a measurable distance and therefore often only afflicts engine parts after several years of use and high mileages – by which time the manufacturers usually don't have enforceable responsibility.

Most engine builders will be aware that some models are very predictable about which areas are affected and soon learn that a particular model needs a specific re-machine in a critical area before re-assembly to result in it being reliable.

(5) How this affects the 9A1 Gen 2 engines is discussed under the heading "Cylinder scoring and seizing Gen 2 9A1 engines (and warm up procedure)".

(g) **Catastrophe theory.**

This is extremely important but very technically and mathematically complex.

There are basically 7 modes of the type of failures and I will leave it to those interested and/or capable of following it to look up the fine details for themselves.

I will try and provide a general basic explanation but there is good material about it on the Internet.

Most graphical failures showing things like load over extension (strain), load over stretch, temperature over expansion etc – follow curves that often start out as straight lines and then towards the end a curve before eventual, gradual and predictable failure.

Catastrophe theory is quite different. In this mode the graph often shows a bowl shape line that as long as the forces, temperatures etc – stay within the scale will not fail and work perfectly OK. There is then another curved line set away from the first one showing the failure results and this line gets very close to the first one but does not touch it (like 2 inverted bowls slightly apart from each other).

What happens is that the very smallest change suddenly makes such a massive difference to the whole system that it jumps imperceptibly quickly from perfectly OK to completely wrecked. I suppose in engine terms a con rod snapping as revs continue to rise too high is a similar (although not very good) analogy.

It does however make diagnosing the cause of faults very difficult because the slightest change in the shortest of times can destroy everything and leave the poor analytical engineer tasked with finding out why with such a lot of debris that the primary cause is often hard to find.

Engine seizures are like this because the smallest change in piston face temperature can micro melt the surface aluminium which then instantly cool as a lump and rubs up and down the cylinder so fast (and at around 100 time/second) that the resulting temperature rise instantly repeats the affect until the whole piston face and cylinder bore are damaged beyond repair in a catastrophe milli-seconds long.

Cylinder cracking and "D" chunking is not like this and we can easily predict the amount of gradual ovality that will soon result in a crack appearing and slowly getting bigger - whereas cylinder scoring IS like this because small pieces of silicon can have often become loose but flow away in the oil to the oil filter resulting in no damage but then suddenly a slightly larger piece or a rectangular piece that tips into a position where it is longest between the mating parts (or has a very sharp edge) catches momentarily and in doing so sticks to the piston and knocks into more silicon particles (that do the same) and in a few milliseconds destroys the piston face and cylinder wall.

HOW THE ABOVE CAUSES INFLUENCE RELIABILITY

(1) IMS bearing.

The feedback for this failure is as follows.

From new most lasted at least 15K (miles).
Some failed at around 45 to 75K, others lasted over 150-200K.

The first double row bearing was replaced by Porsche with a similar sized single row bearing (with similar load ratings due to the sides of the single row bearing being deeper than those in the double row of less than twice the width) but both had similar failure rates. Most of many different ball or roller bearing solutions worked reasonably well but all of them also had some failures. It took a long time to assess the causes of the original failures statistically because some failed at relatively low mileages while others lasted almost indefinitely and so when different new solutions were then fitted to the small number that had failed - later in the life of the car – it took even longer to assess the performance of those smaller numbers of many different solutions – making performance ratings almost impossible. This enabled some new solutions to appear (or be claimed as) more reliable than others.

All we could really offer to this assessment was that we saw some small evidence of all types we are aware of failing except the plain oil pressure fed bearings.

All ball bearings are available with different qualities and clearances. Usually a slacker bearing is also of a lower quality (but not always). The rougher the precision grinding the more wear particles are rubbed off initially and the tighter the bearing internal fit the more will be rubbed off if the fit in the housing squeezes it even tighter together.

We think the original ball bearing was too small for the application. When fitted with an interference (i.e. tight) fit inside its housing the distortion to the thin outer bearing race made some run tighter than others wearing away more metal particles inside the bearing during “running in” than if it had been looser.

Pictures show the intermediate shaft bearing failure and the damaged internals.

The dynamic lateral loads from chain whip may have been higher than expected and the resulting metal contact inside the bearing housing led to premature wear rates and particle loss. Because it was fitted with a seal/cover with grease inside, instead of wear particles being flushed away to the oil filter (as in most oil lubrication systems) those that ran tighter entrapped those metal wear particles inside the bearing forming a grinding paste (that we have physically observed) that then speeded up the wear rates and damaged the balls and tracks.

But – even if the amount of metal wear particles was small - the grease became thin with heat and eventually leaked out of the shield (which is too thin and simple to act as a permanent seal) at which point the badly worn bearings could fail through lack of lubrication and the wear the balls and tracks had experienced. If however the interference fit was not too tight this allowed them to survive better and the wear rate of particles was reduced but they still wore the seal and gradually allowed enough debris to escape and engine oil to seep in and lubricate the bearing again sufficiently to last longer (ball bearings need very little oil to survive).

Removing the old bearing to replace it before it failed (without and engine strip and rebuild) didn't solve the tight fit in the shaft housing nor the resulting distortion and both removing the old bearing and fitting a new one often could make it worse (and after assembly could not be checked) and this placed stresses on the spindle shaft, chains and plastic chain guides that could cause problems later.

Furthermore because the loads were so high - the outside of the outer bearing would often fret against the inside of the hole it was fitted into. This is often called “false Brinelling” (because Brinelling is the result of an impact creating an indentation in a surface whereas the result of this fretting is to transfer some minute metal surface components from one side (say the outer bearing diameter) - onto the other (say the bearing hole) and compact it to the opposite surface. The hard surface of the bearing track can also introduce this fretting because if the loads are too high the harder stiffer surface component is being pushed hard against a substrate that is more flexible gradually working the hard and flexible interface to move against each other until small parts break free.

This has little adverse influence as long as the bearing is not removed (as a piece from one matting face simply gets stuck onto the other mating face in the same space) but if it is – then sliding the old bearing out can score or distort the originally smooth housing and/or some material can remain stuck inside the bearing precision ground hole to distort the new replacement bearing on refitting it and resulting it starting out distorted and pinched from brand new – increasing running in wear particles and shortening its life once again.

Trying to replace a new bearing is also fraught with potential difficulties. You have to remove the chain tensioners so the IMS is not being pulled to one side and then any linear movement of the shaft can push the chain against the grooves it has created in the chain tensioners runners/blades and break small pieces off.

Also - the pinion shaft spigot (to tighten the bearing into the housing) had a sharp recess for an “O” ring seal resulting in a very small area to resist the loads and that created a stress raiser that could fatigue and break. When trying to fit a replacement bearing without stripping the engine - this small shaft had to be pulled against the chain tension to refit the spider into the housing which could initiate a crack leading to fatigue failure later.

The following picture shows the original shaft on the left and our original replacement shaft without the sharp groove for a smaller bearing replacement system.

Ceramic bearings, roller bearings and ball bearings all lasted long enough to appear to be a solution but some still failed after lower or similar mileages that the originals survived for (and often failed for future owners and not the owner when the replacement was fitted – reducing claims).

Oil pressure fed plain bearings can be fitted without stripping the engine and provide an excellent theoretical solution and work well in practice but are very expensive.

Roller chains (fitted to earlier models) have one weakness because as the chain stretches the distance between the rollers increases but as the sprocket wears – the opposite happens and the teeth get circumferentially closer together. This makes the fit less accurate and shifts the loads towards one tooth rather than sharing it among all the teeth.

A “Hivo” chain (fitted to later models) is a very clever design that compensates for this stretch and wear. As the diameter of the sprocket reduces the Hivo chain rolls round a smaller diameter and that changes the angle of the leading edge of the chain plates to move closer together and compensates for wear by presenting a better fit over higher mileages and is therefore longer lasting and quieter.

To take advantage of the benefits of a HIVO chain system - Porsche changed the drive chain from a roller chain to a HIVO chain and later fitted a larger IMS ball bearing which proved excellent (despite still being fitted with a seal). Because the outside of the new bearing was much thicker it resisted distortion on assembly, the new designed clearances reduced the particle wear rates and because the volume of grease and the load capacity was higher - the wear particles were diluted in the grease mix so well that failures are extremely rare. However they could only be fitted when the engine was apart and only to later Hivo chain models.

But the IMS bearings sits low enough in the crankcase to potentially be splash lubricated by the engine oil if the seal is removed. The chains running round the sprockets on the IMS run in the oil bath at speeds up to 40mph and the splash oil resulting is sufficient to enable most older bearings that are still running to survive (with a worn seal) due to the spray oil resulting having a high flow rate and some inertia and finding its way past the worn seal into the bearing. When left idle - oil sits in the lower ball groove awaiting the re-start where it immediately lubricates the bearing with fresh filtered oil minimising start-up wear.

When the problem first emerged - we initially obtained the remaining stock of the small double row bearings from the manufacturers and replaced them together with a stronger spindle (without a stress raiser) and removed the bearing seal which worked very well.

When the double row bearings ran out, we initially replaced them during an engine rebuild with a single row bearing (of similar rating to the double row) and with a different fitting kit – also without the seal – but were reluctant to fit them in situ as a result of the potential damage that doing so could cause and the repercussions if they failed. Although these proved successful they were not considered (or promoted by us) as a permanent solution – just a less expensive and better lubricated one that should as a result last longer but probably not indefinitely.

Lots of alternatives reached the market amid various claims but only of similar long-term reliability because the limited room to fit a ball or roller bearing was simply too small to be 100% reliable. Roller bearings were sometimes used and although these do resist much higher radial loads they have little resistance to axial loads (that chain whip - which we think generates the higher loads - creates). As a result – despite advertised claims to the contrary – we have come across just about every type of ball or roller bearing "upgrade" that has subsequently failed (including ceramic bearings). One video sales pitch even showed the centre of the bearing spinning round and splashing oil out radially into the bearing track as it rotated without realising (or avoiding the fact) that unusually in this particular application the centre of the ball bearing remains static and it is the outside of the bearing that is fitted to the intermediate shaft and that rotates with it – so what seemed like a convincing benefit to promote a product was actually not how it worked at all.

Ball bearings provide good load carrying properties in both radial and axial directions and are really a very good option in this application – the original – just unfortunately being specified a little too small with too thin and too flexible and outer ball track. So because there was space to fit a much bigger and stronger ball bearing - we then manufactured a new end sprocket to fit to the original shafts that could incorporate the larger ball bearing and ran it with no seal and these have proven extremely reliable.

During an engine rebuild - this enabled us to offer alternatives of either our own re-manufactured shafts (for later Hivo shaft engines) or the newer Porsche shaft (both with the same bearing and seal removed).

We then did the same thing but with the earlier roller chain sprocket end to enable owners with the older roller chain drive crankshafts to benefit from the later larger bearing and splash oil lubrication.

The following photo shows the original shaft and small bearing on the left (originally supplied in both roller chain and Hivo chain types), The centre and right hand side examples are our own Hartech re-manufactured shafts to suit the standard larger bearing fitted to both earlier roller chain shafts and later Hivo chain versions (the latter of which is the same as the more expensive Porsche supplied large bearing shaft only available for later engines). We also plugged the shaft to stop old oil collecting in it.

The two bearings shown reveal the difference in basic size and of particular interest should be the difference in the outside diameter thickness showing how much more able the larger bearing outer is to resist distortion on fitting with a tight interference fit into the outer housing.

We think our solution combines the best reliability against cost if the engine is apart and being rebuilt – but we are prepared to fit an LN plain bearing pressurised oil feed kit to an engine that is not due to be stripped and rebuilt - if preferred.

Conclusion

If your car has a small IMS bearing and has covered very low mileage it is unlikely to fail but could do if the original fit of the bearing was tight or distorted in the housing.

If the original has survived for over 80K to 100K it might be less of a risk leaving it alone as very few then fail up to and/or over 150K.

Replacing the bearing needs an experienced person and best to leave the seal off and replace the weak spindle with a stronger one and fit the oil seal that stops oil running out down the shaft somewhere else. Lifespan might be similar to the original (which should be OK for most owners in their ownership).

A pressure fed plain bearing is a good replacement but expensive.

If the engine is being rebuilt we recommend the larger bearing without a seal either the Porsche IMS with the larger bearing (that is only available for later Hivo chain crankshaft drive engines) or our own re-manufactured IMS (which uses the same large bearing but is cheaper and also can fit for either type of chain drive).

(2) **Cylinder cracking and "D" chunking**.

This was easy to solve. Porsche were reported to have limited money available when the engine range was re-designed and had to optimise more modern production techniques and reduce manufacturing costs to survive.

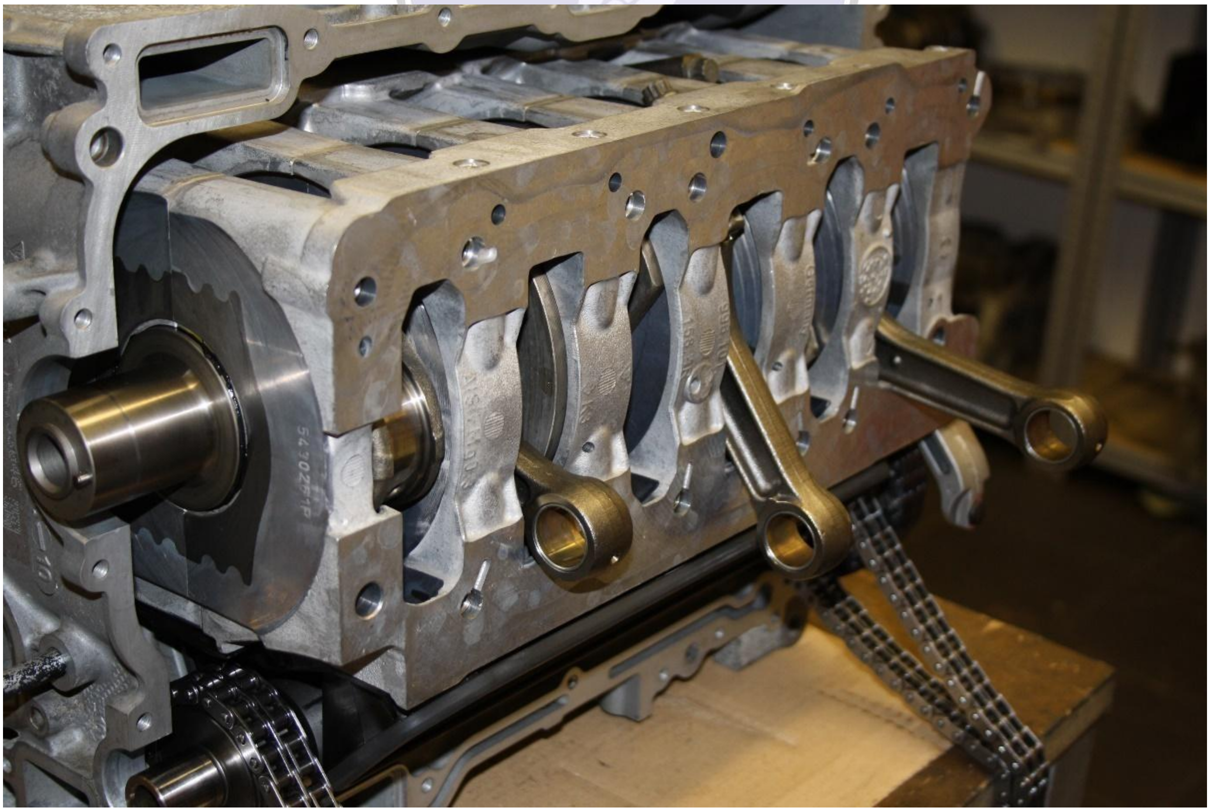
It was clear to us early on that an example of the need to keep costs low was to save investing in different tooling by using the same cylinder head for both sides (or banks) of the engine – thus halving tooling costs and doubling machining numbers. However to achieve this the camshaft drives for each head had to be taken from opposite ends of the crankcase and this forced some other design changes like running one of the camshaft chains at the other end of the crankshaft (which is unusually resulted in the flywheel being less close to the last main bearing – increasing its overhang).

When castings are made for most engines they have internal spaces that are often shaped so they can only be made with hard sand cores. This you could think of a bit like a bottle where if the inside shape was formed by a metal plug – you would be unable to remove it through the top after casting?

The crankcases of this engine range were designed so that they effectively made everything more like a tapered glass (bigger at the open end like a plain drinking glass) so the internal metal mould could still be extracted when the casting solidified. This avoided the time taken with more conventional crankcases with sand cores that have to be vibrated out after casting and increased the accuracy of the casting and as a result needed less machining.

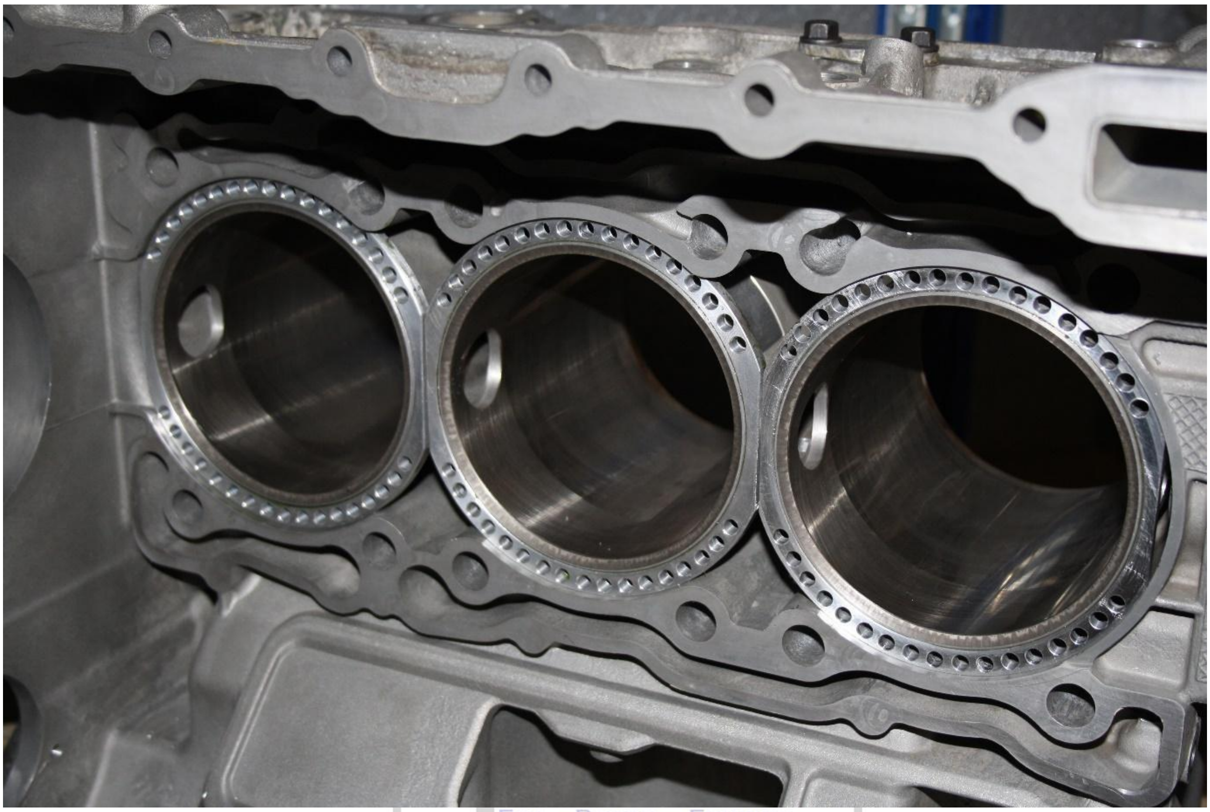
We had seen this technique used before in the 944/968 range (which was cast in Alusil and was a hard very strong and stiff material but slow to machine) and mistakenly assumed that this casting design of the M96/7 crankcases was to reduce production costs, resulting from using metal casting moulds (for greater accuracy and reduced machining material) because they were clearly designed so that metal moulds could be extracted after casting and we thought that this explained the open deck design at the top of the cylinders and the use of a void internally to fit a crankshaft holding cassette.

The following picture shows the 1 half of the crankcase and the crank carrying cassette around which the open bottom of the crankcase halves sit.



The picture below shows that the bottom of the std cylinders are a thin tube with no lower support (just like the standard top).

The cylinder tube is only connected to the rest of the block via a small section just above the middle leaving the top and bottom free to distort. The picture following shows how we fitted precision machined supports to the bottom of our oversized engines (as well as the machined location at the top pictured ahead) so our new cylinders are a true closed deck design, with support top, middle and bottom.



The nearest analogy I can think of for this original design would be a baked bean tin with the top and bottom removed and held between your fingers in the centre while a force is pushed on the inside of the top in one direction – not very well supported or stiff is it?

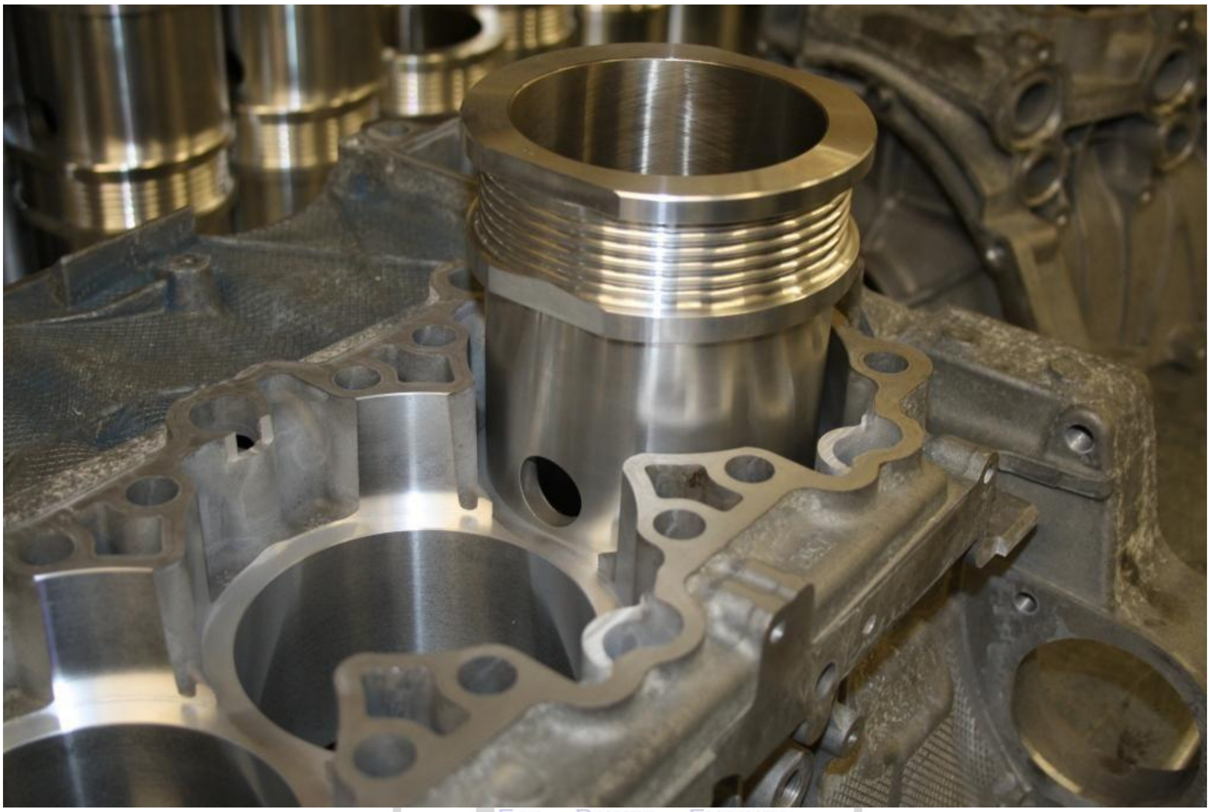
The following picture is the 944 Open deck casting in Alusil but the bottom of these cylinders was fully connected to the rest of the block leaving only the top free.

In both cases a solid metal mould (made up of different pieces that can be withdrawn in different directions) would be able to be extracted after casting.

We knew that unlike the 944/968 most of the M96/7 Lokasil crankcase was standard aluminium alloy (easy and fast to machine) and only the middle of the cylinder tube was described like Alusil (hard with high silicon content) and that this explained the design criteria of Lokasil. What we did not realise at the beginning was that a solid metal mould (and the resulting constraints of an open deck cylinder design) were necessary to enable the high pressures of the Lokasil casting technique to work and were therefore that it was probably not chosen just for the reduced casting costs and machining times – that the choice of Open Deck cylinders was probably because of the Lokasil casting process more than anything else.

The cylinder of the LHS of the picture shows the 2 materials (the centre half darker and Lokasil) and next to it on the RHS a very early Hartech ribbed cylinder manufactured with a high strength alloy casting closing the deck.

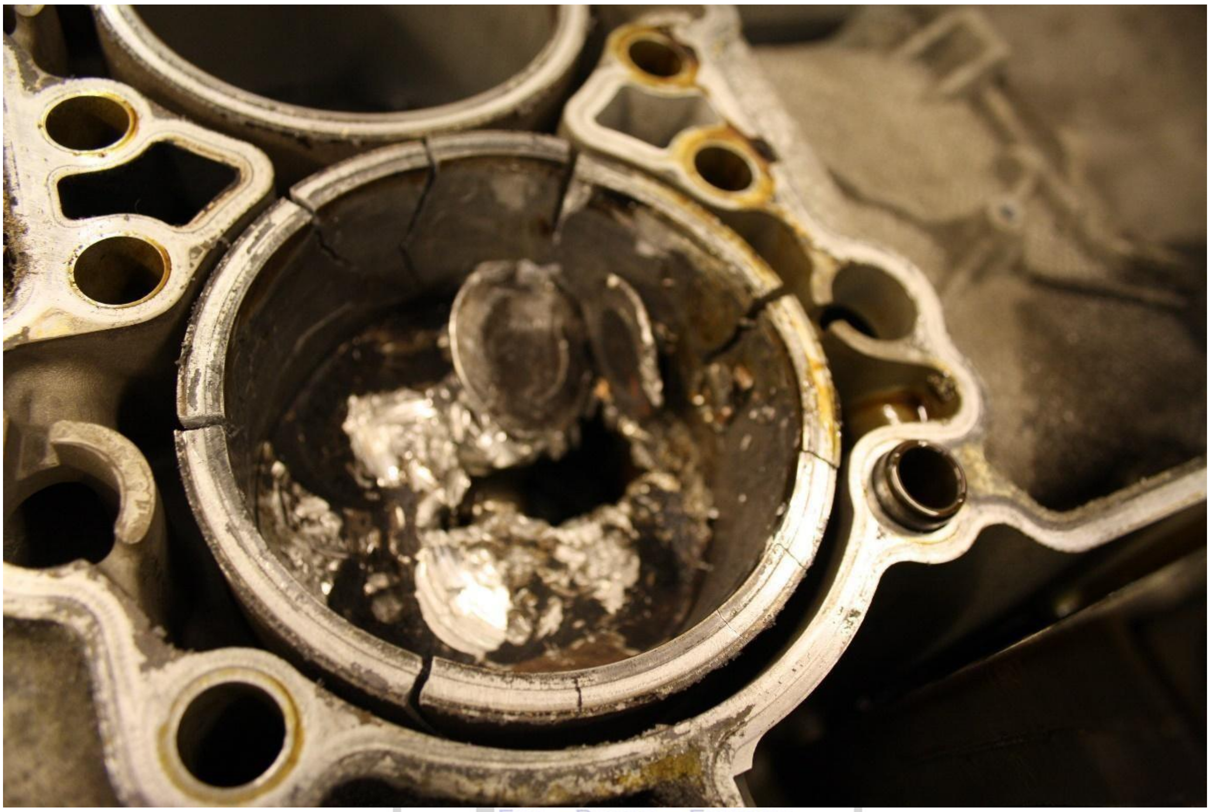
Later Hartech cylinders incorporated improved design features and liners manufactured from billet aerospace alloy - as shown in the following picture that demonstrate not only the increased strength and ribbed exterior but also how the top is bigger in diameter (to keep it round) and how it fits into a precision machined recess to stabilise it from moving under load.



The engines that we initially worked on for IMS failure allowed us to see inside the 2.5, 2.7 and 3.2 Boxster models none of which exhibited any bore cracking or “D” chunking.

Picture following of a 3.4 996 bore well cracked (and off-centre revealing differences in the composition of different parts of the alloy casting strength).

The weakness of the cylinders is also exposed when there is a major failure as shown in the following picture – but even this did not prevent us being able to rebuild the crankcase with new cylinders.



The 3.4 996 was the model that first displayed those weaknesses and we immediately noticed that the cylinder tube had a thinner wall thickness. Further investigation showed that it was basically the 3.2 Boxster S casting bored out 3 mm bigger in diameter to run with the larger 996 3.4 piston and the cylinder tube area was therefore obviously thinner and weaker but trying to resist even higher loads from the more powerful engine.

The following picture shows a Boxster S (on the RHS with the smaller bore and thicker cylinder wall) and 996 3.4 (on the LHS with the same outside cylinder diameter but a larger bore and thinner wall thickness and therefore weaker).

You can see how the 996 3.4 (LHS) is a bored out Boxster S (RHS) with the same external gap between the cylinder and the coolant channels - and following – how the difference could easily be measured.

Measuring the bores showed that because the piston forces only apply to the opposite sides of the cylinder tube - they had gradually changed shape to oval and were wider in one direction (where the thrust occurs) and narrower in the other. Because pistons are also made oval there was no problem with the narrower dimension pinching the sides of the pistons (because they were already narrower) but the wider area eventually stretched the material too far at the unsupported top and cracks would appear.

Cracks shown below leading to a chunk eventually breaking free.

Picture showing a typical single cracked cylinder block

Comparing the different cylinder wall thicknesses of different models we found the 2.5/2.7 has a Lokasil wall thickness of about 2.75mm (hence an aluminium thickness of 5.25mm (total 8mm).

The 3.2 has a Lokasil wall thickness of about 2.75mm (hence an aluminium thickness of 6mm – or 12.5% thicker and a total of 8.75mm). So far this would predict that both would be reasonably as reliable as each other.

The 3.4 has a similar Lokasil wall thickness as a 3.2 @ 2.75mm, but because the overall wall thickness is less (only 7,5mm) the supporting aluminium wall thickness is much less at only 4.75mm – which is 10% less than the 2.5/2.7 and a massive 21% less than the 3.2 engine.
So if – because of creep and lower initial strength – the main resistance to the cylinder liner stretching is provided by the outer aluminium cast cylinder – the 3.4 has reduced its influence by about 21% while increasing the forces by 20% (from the amount of power increase). Let's round up on a figure of say 10% extra load for a 3.4 over a 3.2. If so this means that the 3.4 has a generally weaker resistance to cracking (if we ignore the contribution of the Lokasil liner) of around about 40%. Well the Lokasil must have some contribution – but from these calculations the reduction in cylinder liner strength, stiffness, creep resistance or fatigue resistance of the 3.4 engine over the smaller Boxster engines must be somewhere between 20 % and 40% - I would guess about 25% less and like all fatigue failures, the nearer you get to a failure cross sectional area the faster the fault emerges.

To establish the material strengths we cut out pieces of the base alloy and the Lokasil bore material to tensile test and found the alloy normal for aluminium crankcases but the Lokasil stiff and brittle – the combination of both and the thinner cross sectional thickness combined with the higher loads imparted from the more powerful engine (and heavier pistons) exceeded the yield point leading to ovality and eventual cracking.

Picture shows one of the sections we cut out.

The following picture of the Lokasil portion after testing for bending resistance shows that it had a brittleness that cracked the section out before the circular tube permanently distorted (which aluminium by comparison would just bend or crush permanently oval before breaking). The cracked area clearly shows the crystalline structure in Lokasil even at this low magnification.

We also tested the Lokasil portion for compressive strength and found that although it was initially stiff it suddenly collapsed much thinner (due to porosity) which solid aluminium would not do so at all. It reminded me of a chocolate Aero bar (which is full of air bubbles) and if squeezed will initially resist and then suddenly crush. The presence of porosity was also confirmed via a density test and meant that there was still porosity present.

We found that once the bores had crept oval by 10 thou (0.25mm) they would soon predictably crack and in the same block some had crept by 4 or 5 thou while other cylinders by 8 or 10 thou confirming that there was a variation in the stiffness of some cylinders compared with others due we thought to different distributions of the silicon content internally varying the strength of the Lokasil half of the cylinder tube (because the aluminium would reasonably be expected to be the same).

Picture showing uneven Lokasil distribution in the cylinder.

We had a mix of failures (some cracked in a line and some in which a chunk had cracked out) so because the forces from each cylinder would be very similar – we assumed the differences in the places that cracks initiated must be due to differences in the silicon distribution in the pre-formed Lokasil tubes.

Since it would not be possible to fit a liner inside a cylinder tube that had already cracked or “D” chunked, we developed a solution to machine out and replace the whole cylinder and influenced by the design and development work undertaken successfully by me decades before (doing the same thing for 2 stroke racing engines) we already knew that the best solution was an aerospace alloy replacement cylinder with a Nikasil bore and supported top hat to convert the block to a closed deck design to stabilise any potential cylinder movement or distortion. With the more powerful but expensive 996 turbo and GT3 engines also using alloy Nikasil plated closed deck liners (very similar to our own) we were confident that our solution would be the best option on the market (as it has proven in the following years).

Picture of the Armstrong 250cc GP cylinder (with Nikasil bore) designed by me in the early 1980's demonstrating the bigger top hat section and connection to the outer cylinder (to close the deck) while creating space for coolant (very similar in concept to our present Hartech closed deck cylinders).

We were also influenced by prior knowledge that although ferrous (iron or steel) cylinders can work well for racing (if the cylinder block design is suitable and because for racing heat and expansion is constant and greater cold running clearances are irrelevant) they were not as suitable for road car applications (where clearances vary hugely at different performance levels).

But it is essential when fitting ferrous liners that the material of the cylinder block is suitable in design with the most reliable being fitted into closed deck cylinders so there is support with an interference fit throughout the whole liner top to bottom. With this particular cylinder block design - as the existing alloy cylinder tube was already proven to be too weak and unsupported - we knew that fitting a stiff ferrous liner inside would allow the piston forces to push the liner against the now much thinner and even weaker alloy exterior and stretch it until it also went oval and the liner could become loose, distort the bore shape and potentially drop and cause head sealing failures while limiting heat transfer.

Thin, ribbed “cast in” iron liners can work well in closed deck applications and if the piston diameter is not too large (so the difference in thermal expansion and contraction between iron and aluminium is limited) and because the ribs help the aluminium to stretch the iron under thermal expansion without losing contact or the “fit”.

Unfortunately it proved easy for some competitors to persuade owners who were already struggling with the unexpected cost of a rebuild, that iron liners were ok and slightly cheaper putting our warnings of unsuitability down to salesmanship. But soon afterwards engines starting to come to us for a second rebuild once the owners realised their mistake and were not going to repeat it a second time.

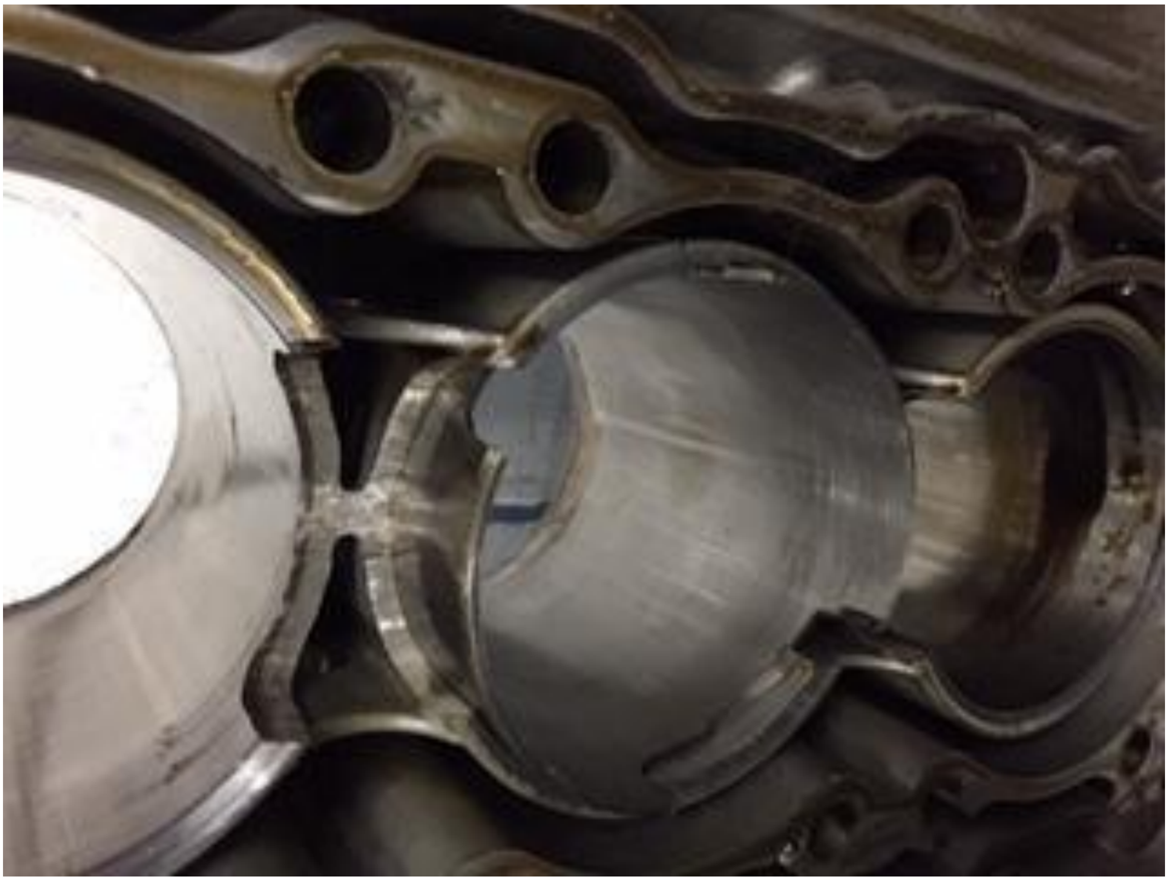
This blew the argument away that we had simply been applying salesmanship since we then received almost all the failed engines for a proper 2nd rebuild (making it more in our interest to ignore the advice and await the second rebuilds coming to us) – but still the public seemed easily persuaded that iron liners were OK.

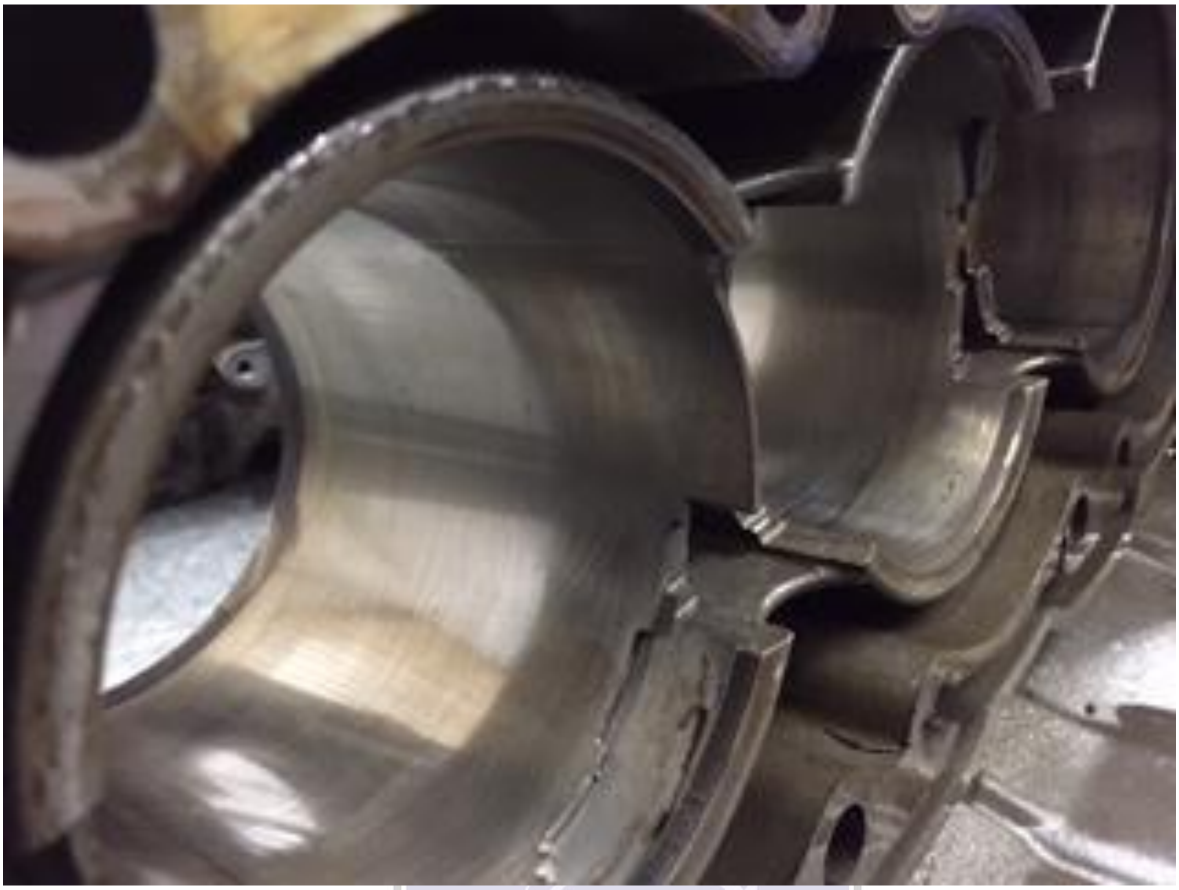
It was unfortunate that this also put us at odds with iron liner suppliers when there is nothing wrong with their product or using them in the right applications – but this is not in our opinion – one of them.

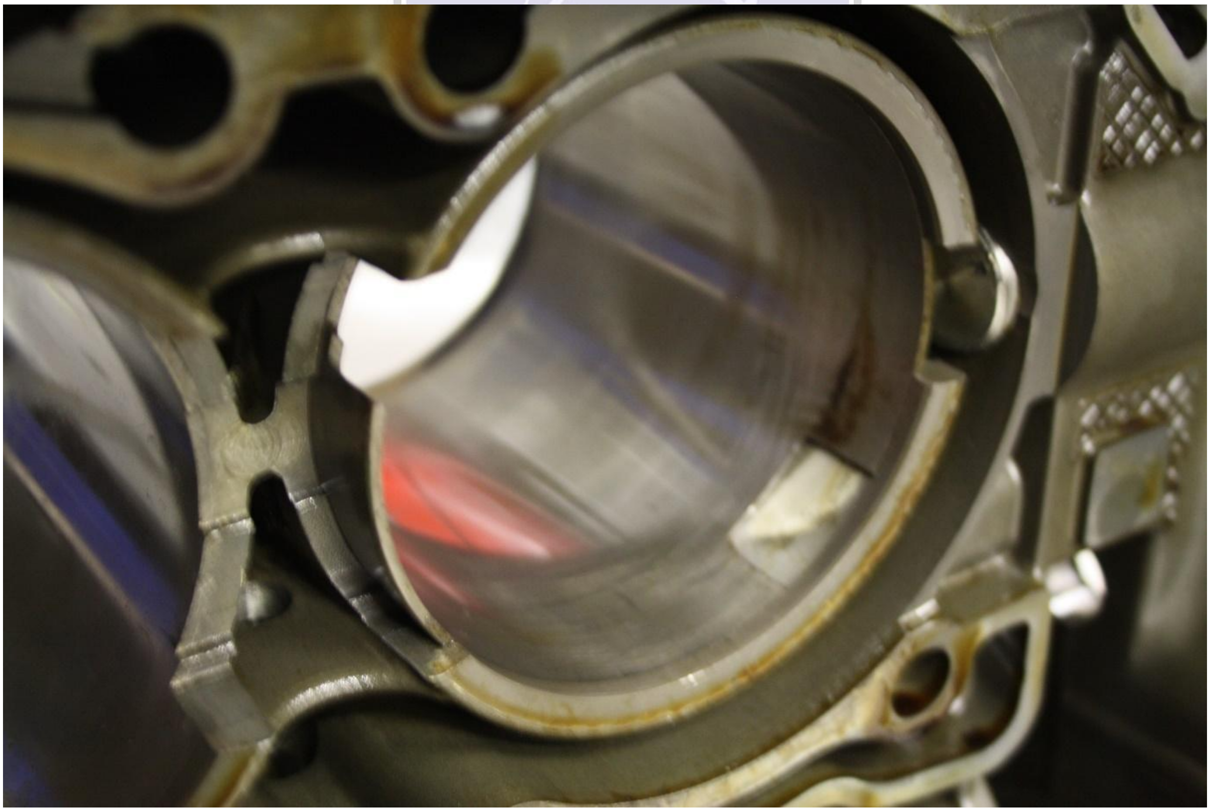
One difficulty is also that supplying iron liners to different engine rebuild shops resulted in a lot of different ways to try and make them work, few worked out by qualified professional engineers and each working in small numbers with less feedback and not totally responsible for the rebuild or able to limit any resulting claims to fitting the liners (and not the whole rebuild).

But let me show you some photos for you to make up your own minds. You may well recognise how similar some of them are to photos advertising them in Porsche magazines.

This first three show several issues – how thin both the liners and the original sleeves are once they have been machined out, and how the liner became loose when the cylinder expanded and twisted when the rings ran against the honing angles while it was loose.

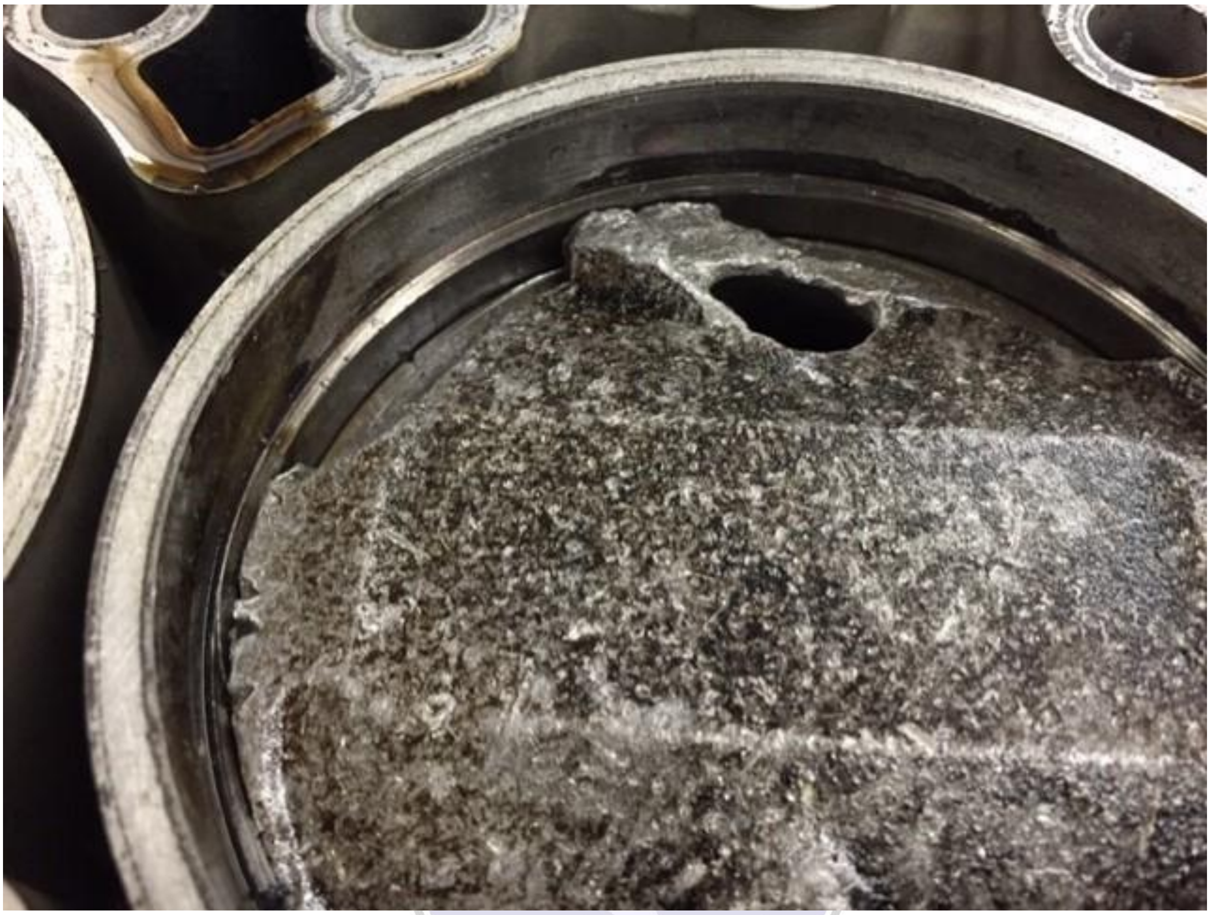






The next picture shows how once the crankcases expanded with heat – all three liners have slipped down from the top due to how thin and weak the outer remaining aluminium was and how the coolant had then got past the head gasket and corroded the bores.

This next picture also shows a liner that has slipped down and what can happen as a result.



We have many more examples and so many old iron liners that we no longer bother to keep them – but this next photo just shows how far some repairers go to try and bodge the repair by trying to weld the bottom of the alloy block – to stop the liner slipping down – and you can see that despite this it still seized to the piston at the bottom. How would you feel if you had paid for a rebuild of this standard - just absolutely horrendous.

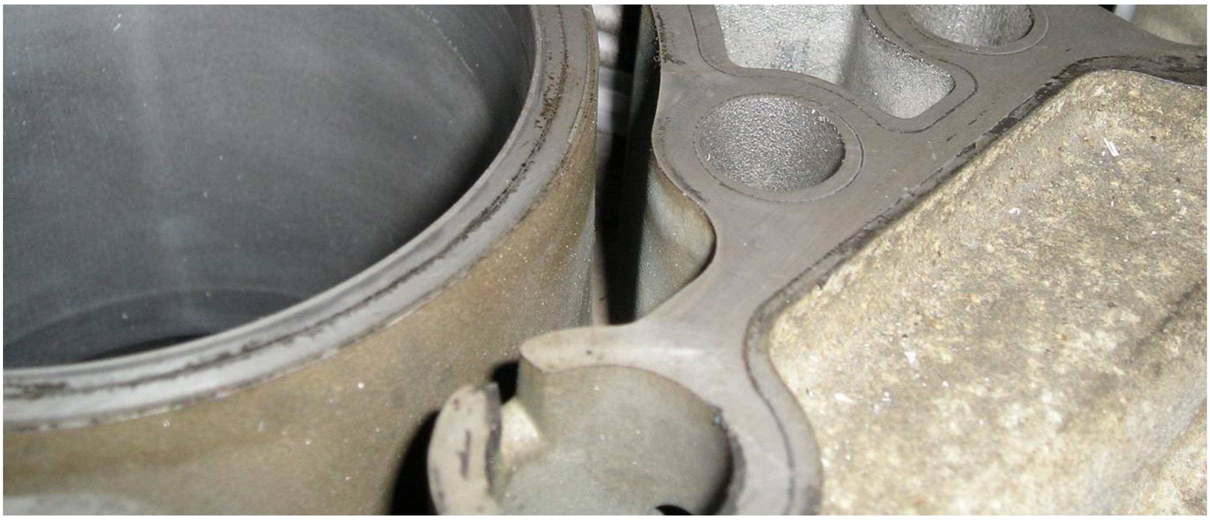
What do you think of that evidence? Do you now put our warnings down to salesmanship or scare mongering OR genuine concern to try and protect owners from making a choice that does not suit this cylinder block design or construction? You will not be surprised to learn that we still have lots more examples of this where previous ferrous liner replacements carried out elsewhere - subsequently failed.

We understood the unsuitability of this particular-open deck cylinder block design for iron liners - right from first observing the cylinder block design and past experience of fitting iron liners – so knew (as was later proven) that it was not going to be a good solution. But most engine repair shops are used to fitting iron liners and of course some competitors want the business for themselves and not to support a better solution that involves others and can be more important to them than the outcome.

Our solution is absolutely the best available, well proven and based on years of experience that would usually cost far more than we charge because it usually involves a number of different businesses to carry out the different types of machining and assembly work – which we have brought all IN HOUSE and tooled up for and streamlined so we can offer it at competitive prices.

One of the other design issues we noticed was that the depth inside the cylinder was extremely shallow and that unlike the 944/968 design (where 100% of the coolant flowed first into the cylinder block) the amount of coolant directed into the cylinder block was only about 10% of the total (the rest directed into the cylinder heads) and that this inevitably would reduce cooling efficiency. We felt the coolant flow volume was too small so to improve this we designed our replacement cylinders to be wet cylinders (completely replacing the original duplex material cylinders) and with external ribs (to increase the cooling surface area).

The picture below shows at the bottom centre of the picture - the round channel for coolant to flow straight up into the cylinder head of each cylinder and the tiny rectangular slot allowing a very small proportion to flow at right angles into the cylinder block to cool the cylinders.

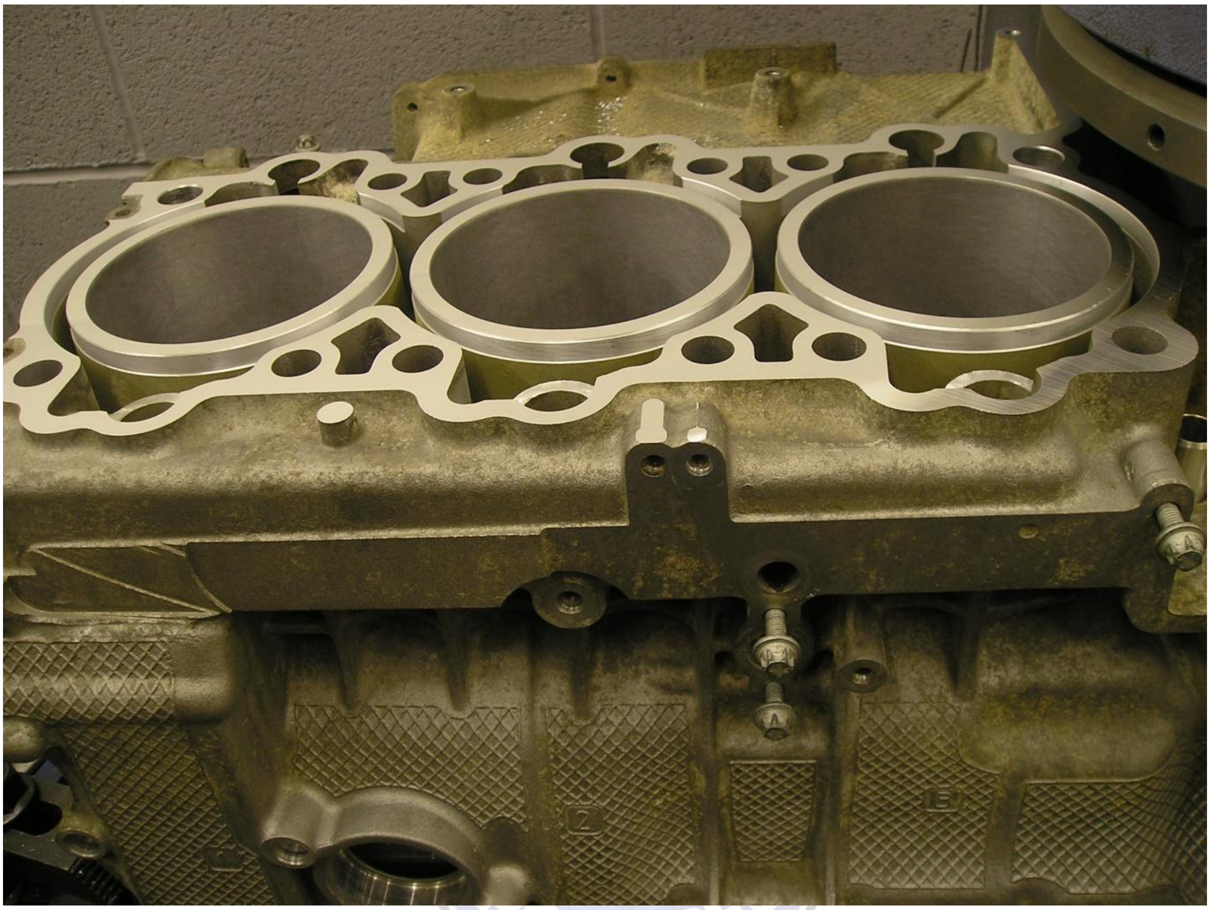


We also noticed that by a huge piece of luck the external top of the cylinder block was largely round and could be machined so that our liners could be made with a “top hat flange” as a precision fit inside the block, supporting the cylinder. The extra diameter of the top hat would stiffen our cylinder tube further and being connected to the external block would convert the design to a closed deck and create a much improved cylinder design, while using aluminium would benefit expansion rates and cooling efficiency enabling the right cylinder clearances both when driving hard (and fast) and slow (and cooler – unlike a ferrous liner).

We set up a precision machine shop to carry out all the work internally and the result was 100% reliable (as expected) and to date has successfully repaired thousands of cylinders.

But some owners simply didn’t have the financial resources to pay for all 6 cylinders when only one had cracked – so for owners who could not afford to replace cylinders not yet cracked or “D” chunked, we created support rings to fit at the top of existing cylinders that also fitted our precision machined locations (to convert them to closed deck and stop any further movement or cracks) and developed a technique to reduce the existing ovality at the same time (to improve cylinder roundness, clearances and reduce blow by).

The following picture shows the machined diameters on the outside of the top of the cylinders and the inside of the top of the cylinder block - to fit support rings shown above the cylinders awaiting machining flats on and fitting.



Many however will be unaware that you cannot simply machine a full 360 degree round diameter into the top of the cylinder block (or you would machine away part of the adjacent cylinder) and this is why our rings and liner tops have flats machined on the sides where no load is imparted by the pistons). This practical problem prevents reconditioning shops with conventional boring machines from creating the circular curves necessary to convert the top of the block to a closed deck to support the top of the liners. This machining can only be carried out by a method using – for example – accurate computer numerical controlled (CNC) milling machines – which we have in our workshops (but most engine reconditioning workshops do not).

The combination of these designs resulted in the best repairs on the market and (as far as we are aware) are still the only ones that are solid alloy Nikasil liners (more properly new cylinders) and convert to a wet closed deck or stiffen existing cylinders with a support ring.

Despite warning about this potential problem we still receive a large number of engines to repair for the second time that were repaired with ferrous liners. Some had thin ferrous liners that were so thin the alloy crushed them after fitting (as the block cooled) such that the interference fit was reduced so much that when hot the alloy block expanded so much compared to the ferrous liner that the liner became loose and dropped or rotated. Others were thicker – but that meant that the remaining alloy tube holding them in place was even thinner and even weaker allowing the liner to eventually stretch the outer aluminium intended to hold it in place and become loose, especially at the top.

Some had a bigger top hat (mimicking ours) but did not fit to a machined recess (although they were often made to look like they did). One reason for this deception could be that many engine reconditioning shops only have equipment to machine round holes and the machining of the external top of a recess to fit a top hat diameter to cannot be accurately carried out with this type of equipment. Similarly many do not have accurate enough machinery to create a shoulder to sit the liner against to prevent vertical/linear movement that allows creep of the liner position after heating and cooling.

So even these liners with large top hat sections didn't convert the block to a closed deck, didn't have external ribs, and still could never have the right hot and cool piston clearances (that were the main reason behind all sports car manufacturers that were using large pistons to combine them with alloy blocks of one kind or another).

The following picture is a small selection of a 3 figure number of replaced ferrous liners that we retained showing 3 of 11 different versions all of which eventually failed and required replacement while several thousand of our alloy Nikasil liners have never suffered any retention problems.

The next picture shows some of the variety of iron liner designs that failed.

We regret that this led to rivalry between us and suppliers of ferrous liners (that in many closed deck applications – especially using smaller diameter pistons – can be perfectly acceptable) and how we felt that this was unfortunate because we have nothing against the use of ferrous liners in the right applications – but this is just not one of them. The size and design of the pistons and the cylinder block simply are not ideal for them. To help prevent owners from choosing the wrong solution on cost grounds that they might later regret - using CNC machinery IN HOUSE we managed to reduce the price of our Nikasil alloy replacement cylinders/liners to almost to the same level as our ferrous liner competitors.

After fitting thousands of our Nikasil plated aerospace aluminium ribbed closed deck cylinders with 100% reliability, and having streamlined production to be able to offer this fool proof solution at very modest costs, we would not want to risk the potential problems that would result in failures of new alternatives about which we have doubts that only much more time and feedback will contribute to even though it would probably be more profitable to do so as our replacement cylinders are many times more expensive to manufacture.

Now – years later – wide-spread approval of our solution means that we no longer need to promote the benefits ourselves as a huge number of satisfied customers have done so through their own experiences and satisfaction.

When we became too busy to manufacture enough of the alloy cylinders IN HOUSE ourselves - we sub-contracted them under licence to a supplier with extensive experience of manufacturing the same type of liner for (F1 and Mclaren cars etc) and established a superb trading partnership that later expanded into different models, oversized engines and matching pistons.

Most customers now accept the benefits and longevity of our rebuilds and prefer to have all 6 cylinders replaced while the engine is being rebuilt (for which we offer a discount pricing structure) and many have since covered much higher mileages than their original new engine survived for before failure, are still running perfectly and command a better re-sale price as a result. We also export to both agents and private individuals all over the World and are co-operating with a Canadian agent to carry out the machining and fitting of our liners under licence over there (to avoid the cost of crankcase transportation).

Conclusion.

Most 996 3.4 engines will experience cylinder ovality leading to cracks or "D" chunking. How long it takes depends upon the quality and distribution of silicon in the original crankcase casting and the average power it was driven with during its lifetime (introducing 2 variables that in different combinations make failure mileages impossible to predict).

However we find that many will fail after 100 to 150K of average use.

Replacing the damaged bore with an aerospace alloy closed deck wet Nikasil plated liner is the best solution while ferrous liners (iron or steel) are not recommended by us.

We recommend replacing all 6 liners and offer a discount for owners choosing to do so and subsequent re-sale prices are then higher .

We can fit cylinder supports to un- cracked Lokasil liners but they will have more clearance than a new liner, may run more lumpily as a result and will probably still fail but only after covering very much higher mileages.

We also make a 3.7 conversion available raising a 3.2 Boxster S or 996 3.4 to the performance levels similar to a later 3.6. We also fit a lower support ring with these conversions to render the cylinder supported top, middle and bottom.

(3) Cylinder scoring M96/7 3.4, 3.6 and 3.8 engines.

The bore scoring that became probably the most common fault some years later (afflicting 3.6, 3.8 and Cayman S engines) was a much more difficult problem to understand and we don't mind admitting that we did not initially work out the causes correctly. It took a few years and a huge investigation, testing, stripping and rebuilding engines, communicating with the manufacturers, researching technical issues and head scratching to get to the bottom of it. During this process we considered other explanations that we now read others proposing who have not continued to investigate as thoroughly as we have and have not yet reached our final conclusions.

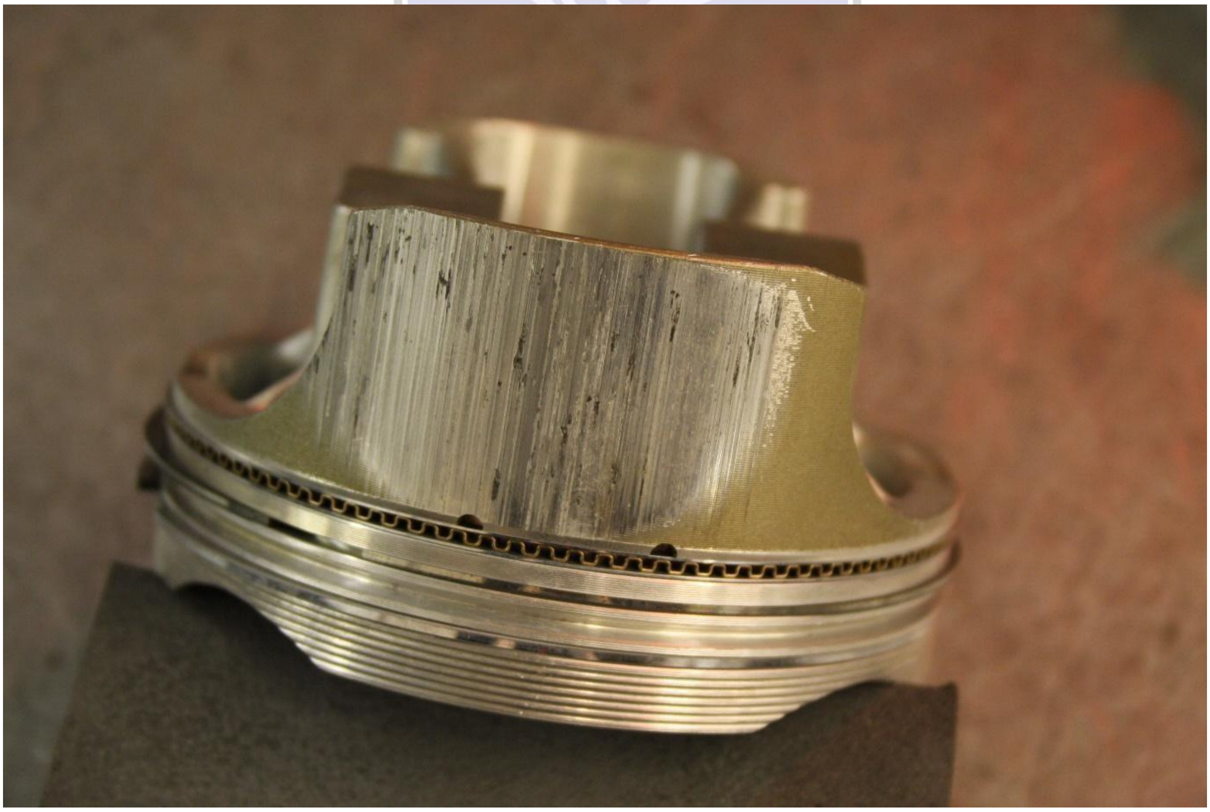
Fortunately this didn't affect our ability to repair engines because we already had at our disposal the best solution (our proven replacement cylinders initially used for cracked or "D" chunked engines) which we used for this different failure mode as well. This enabled us to provide the same solution regardless of the cause being cracks, "D" chunks or scoring – which therefore utilised the same processes, parts and tooling and benefitted from the same economies of scale out high turnover was enjoying.

However using this original solution did not stop us exploring a number of potentially less expensive alternatives. Although we eventually understood the problem (many years ago now) we are disappointed at how long it all took to evaluate all the contributory factors – but with Porsche continuing to sell the same product (and providing no technical assistance) we were on our own and anyway (and as if to confirm how difficult the whole situation was to bottom) we see no evidence that anyone else has worked out the actual cause correctly yet - while many others suggest various alternatives that we have already disproved, that make no sense or contain no correlation to all the historical evidence.

We did notice straight away that the scoring was unlike a seizure (where the piston expands more than the cylinder bore and therefore seizes the piston and bore surface on both sides as a result of metal to metal contact) but the scores were only on the side of the piston that pushed the crankshaft round (via the con-rod) under load – which we had not seen before (and had only heard about afflicting larger diesel engines) with only a couple of exceptions when older 944 S2 high mileage engines occasionally scored (usually more on the thrust side than the opposite side – sometimes only on one side) even more rarely afflicting high mileage 968's. This is very unusual because while it is possible to imagine why a piston that has for some reason expanded bigger than the cylinder bore would have no clearance for an oil film and rub 2 dissimilar metals together hard, overheating the surfaces and leading to micro welding and seizures – it was difficult to understand how one side of the piston can be rubbing hard enough to cause scoring while the other side is unaffected and running perfectly.

Typical bore scoring picture showing how the top (where the piston is machined very much smaller) was hardly scored but the rings still carried debris to the top. This scoring is only on the thrust side of the cylinder bore.

A typical scored piston (notice the black flecks in the surface).



The top of a piston (where the rings fit) is machined much smaller than the body under the rings so rarely touches the cylinder and this can be seen in the above photos.

The problem with the older 944 S2 engines was clear. Although the coolant depth was reduced compared to the earlier 944 engines - 100% of the coolant flow ran into the front of the cylinder block and backwards warming up as it absorbed heat progressively from cylinder 1 back to cylinder 4 through the block first – only then did it flow up to the cylinder head and finally back to the front through the head in the reverse direction (4 back to 1) and to the outlet.

This flow was controlled by the head gasket which eventually perished and when it did the places where it blocked the flow from rising up into the head too soon - disappeared and the coolant flow short circuited and just flowed from the front one or two cylinders straight up to the head and forward to the outlet – leaving the rear cylinders with little or no flow - getting too hot, the oil too thin, the clearance between the cylinder and the piston too small and the surfaces interfering at a time when the piston coating had worn down and the silicon crystals were more exposed. This meant that we were already aware that higher than normal coolant temperatures could increase the local oil temperature and run the oil too hot and therefore too thin to create a thick enough oil film to keep the rubbing surfaces apart and that temperatures may offer a clue to the problem (although the M96/7 had individual coolant feeds to each cylinder and would not be affected by the same issue).

Returning to consider the failures in the M96/7 engines - we also knew that although fitting a thinner unsupported dry alloy Nikasil liner could be an option, two tubes inside each other are not as stiff as one tube of the same overall major and minor diameters and thermal cooling rates are less when two separate material faces create an interface between them. Since the 2 tubes resulting would still incorporate an open deck construction we reverted to continuing to offer our (by now) well proven solution for bore cracking and "D" chunking by producing the same type of closed deck liner that was so successful. Meanwhile the increased volume of liners to suit both models helped reduce production costs and allow this much superior solution to compete with inferior ones.

However - although we could machine the liner out and replace it with our own Nikasil versions – we also noticed (and measurements confirmed) that the Cayman S, 3.6 and 3.8 cylinders had not stretched as oval as earlier 3.4 996 crankcase models (despite the cylinders being no thicker than the 3.4 996 ones that stretched and cracked with less potential forces than from these more powerful engines). This suggested a change had been made to the casting mix in a second version of Lokasil to stiffen those cylinders more.

With customers always seeking a less expensive solution (and with us always trying to help them) since the later cylinder tubes were clearly stronger than the earlier ones - we thought an alternative might be to fit our M96 3.4 top support rings (converting them to a closed deck) and simply bore out through the scored Lokasil bores (as the hard Lokasil portion was thick enough), re-hone them and fit slightly larger diameter specially manufactured oversized pistons.

We thought we could then still offer replacement alternatives with our ultrareliable and long lasting Hartech cylinders (using standard pistons especially as at least 4 or 5 would still be undamaged) as one option or reboring (with new slightly larger pistons) as another cheaper one. We also noticed that the original piston supplier had been changed from the same manufacturer of the Lokasil cylinder blocks and that standard pistons from the new supplier now appeared to have a different coloured coating in precisely the areas of the thrust face patches – which we assumed was a technical improvement.

A reliable specialist piston manufacturer confirmed that their pistons had a coating that would work perfectly with Lokasil and so we had some special oversized pistons made, invested in a new honing machine, obtained the right very expensive honing diamond and exposing hones and tested the outcome (which seemed to work perfectly initially leading to orders from us for a range of more slightly oversized pistons).

However trying to reproduce faults that only reveal themselves after many years, miles and heat/cool cycles is not easy in a short period (especially for small businesses) and after many more thousands of reliable miles - the test engine started smoking and upon stripping we found a piston and bore had scored again (and at much too low a mileage to provide a reliable repair solution).

So we contacted the company in Germany who manufactured the Lokasil crankcases for Porsche (K S Kolbenschmidt) – and who also manufactured the original pistons (that did not score) to ask for help. They were understandably cautious but did provide a lot of clues and technical input (that included and confirmed that our honing was spot on and therefore not the cause) without admitting too much that might land them with any kind of liability. They did however immediately state that **pistons would not work long term in a Lokasil bore unless they had a hard ferrous coating** (which their pistons that used to be original equipment had and didn't score bores) and our specially made oversized pistons (and the new OEM plastic coated pistons) **did not** have and **did still score bores** – so that piece of advice seemed reliable (and proved to be so).

Meanwhile - some specialists have linked the fact that the earlier KS pistons were cast (and the later replacements forged) linking the failures to the manufacturing differences without realising that at the very same change point hard iron coatings on the cast pistons were replaced with softer, inferior, plastic ones on the forged examples from a different supplier and that it was the change in coating that was relevant and not the change from cast to forged pistons.

This simply meant that we had to revert to our ultra-reliable replacement liner as the only solution we could offer – while we started a very lengthy investigation pulling in all kinds of anecdotal evidence, technical research and practical testing to find out the real cause.

We were also aware that a newer solution of direct Nikasil plating over the original scored bore was now available from some sources. We considered this option but although it had not been on the market long enough to assess long term reliability there were a number of reasons why we do not like the whole idea.

(1) For all M96/7 engines it does nothing to avoid the original cylinders gradually going oval and eventually cracking or "D" chunking.
(2) For 9A1 Gen 2 engines the oil spray jets get in the way of final honing back to size while the lower main bearing casting prevents the hone passing the bottom areas.
(3) The damage caused during scoring or seizing results in extremely high temperature local hot spots in the aluminium bores that distorts the surfaces on cooling and results in localised highly thermally stressed areas underneath the new plating that we feel might end up age stress relieving and either changing the bore shapes and sizes or loosening the plating.
(4) The oil (or the additives or Nano particles) that will have been running in the cylinders for a long time may not be able to be entirely removed from all the various porous surfaces and if so some electroplating bonding may suffer.
(5) The variation in surface composition that we have identified in Lokasil may have an influence on the consistency of any newly plated surface

coating over it especially if the scored area failed first because of the variation in silicon distribution that we have already identified.

(6) We are already aware of some that have failed and others where the plating was difficult to bond to some castings.

(7) Alumium is flexible and solid - but not compressible whereas Loaksil is not flexible but is compressible and Nikasil is hard, non compressible and not very flexible at all (easily chipped) so all three co-joined surfaces have completely different structural resistance to loads. We are concerned that with the cylinders remaining flexible from the piston's thrust loads, the three different materials all being subjected to the same compressive surface loads and all with different stiffnesses or flexibility, may – over a period of time - debond the new Nikasil from the Lokasil substrate, causing damage.

(8) Who would carry the cost of a full engine removal, strip, repair and reinstatement if it failed and what solution would then result?

As we already have a proven successful solution replacing several thousand of our Hartech cylinders (and over a thousand rebuilds) with no warranty or guarantee issues resulting - we are not prepared to take the risk of this new solution and continue to recommend ours while continuing to keep an open mind and to explore other options and await long term feedback.

The manual from K S (K S Reconditioning of Aluminium Engines) confirmed most of what we already knew. It contains pictures of open and closed deck cylinders, explanations of the different processes and was very comprehensive.

Comparing the differences between Alusil and Lokasil - KS claim that although "the 2 processes differ considerably in the casting technologies used - on finished surfaces, the differences are insignificant." What they were basically claiming was that although the 2 manufacturing processes were different – the outcome was the same in practice and operation. In our experiences this is now demonstrably optimistic (although to be fair to them they always stated to us that Lokasil had to be combined with hard ferrous coated pistons to work.

We think the fact that Alusil is much stiffer was also possibly overlooked when the thinner cylinder wall 996 3.4 was introduced (although we don't know who made that decision – them or Porsche but by increasing the capacity and piston diameters – the remaining spaces for coolant were being reduced pro rata so there was a limit and something had to be compromised) and although KS continued to make cylinder blocks for Porsche with Lokasil bores – they did not supply the pistons with the softer plastic coatings for the engines that scored bores (which we think must be significant).

Although it has been very unusual for us to take so long to diagnose the causes of a problem - the above situation (that was entirely out of our control relying on public information declaring that Alusil and Lokasil were effectively the same thing - that we think was eventually proved to be misleading) combined with the confidence our oversized piston manufacturer had in the suitability of their plastic piston coating in Lokasil - also explains why it took a long time to identify the issues and why we were initially misled about the direction we took to explore repair solutions and finally had to work out for ourselves what the issues were (and we were not alone as the same specialist piston manufacturer that originally claimed their coatings would be suitable for Lokasil now state on the piston boxes that they **are not suitable for Alusil or Lokasil)** so hopefully we all learned something valuable in the process.

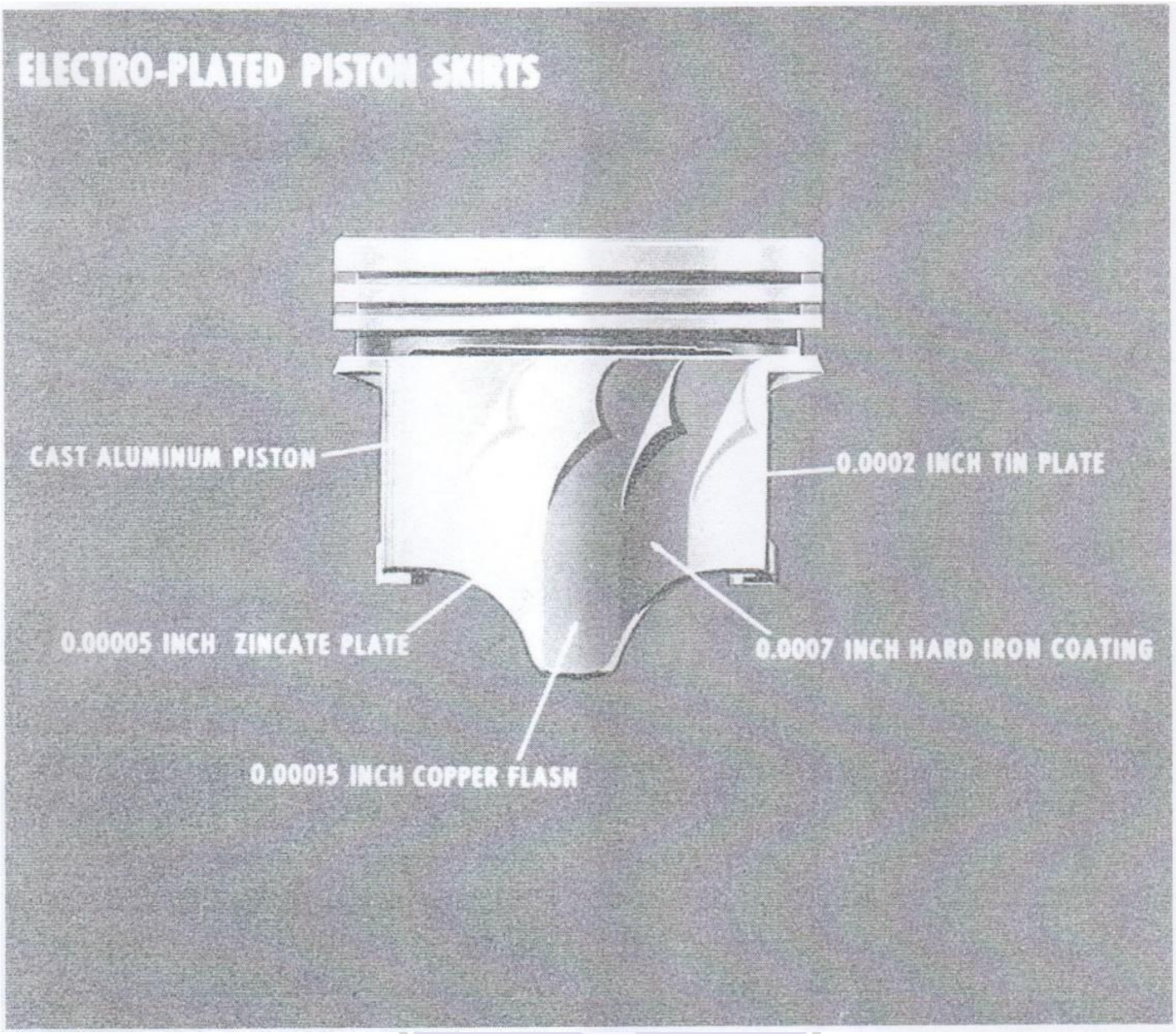
Although Nikasil plating was discussed in the comprehensive K S manual it was not as well promoted as the World at large has found it to be (nor as much as history has proven with Porsche's own 911 air cooled and GT3 and turbo engines – and the majority of F1 engines for decades – where it has been pretty well foolproof and very long lasting) resulting in Nikasil being universally recognised as the best cylinder surface finish possible (but we do not think it is something that is offered by KS).

Although numerous repair solutions were also covered it did not include removal (or machining out) of the whole original cylinder casting area and replacement with a new wet alloy Nikasil liner (which we had already used successfully for repairing cracked and "D" chunked engines).

Despite confirming the benefits of a closed deck cylinder - their manual therefore did not mention or evaluate an aerospace aluminium thicker ribbed wet liner with a Nikasil bore finish (as supplied by ourselves) despite it being proven to be a totally reliable and long lasting solution by eliminating all the weaknesses of the original design.

Although our replacement cylinders were a very successful solution - we simultaneously continued to research several different areas to try and understand the problem that seemed back then to only afflict bank 2 – which was odd. We had to work out what was it about bank 2 that was different enough to bank 1 to make the differences in failures only being on bank 2 side? We thought that understanding this may also throw light on the reasons for the failures overall.

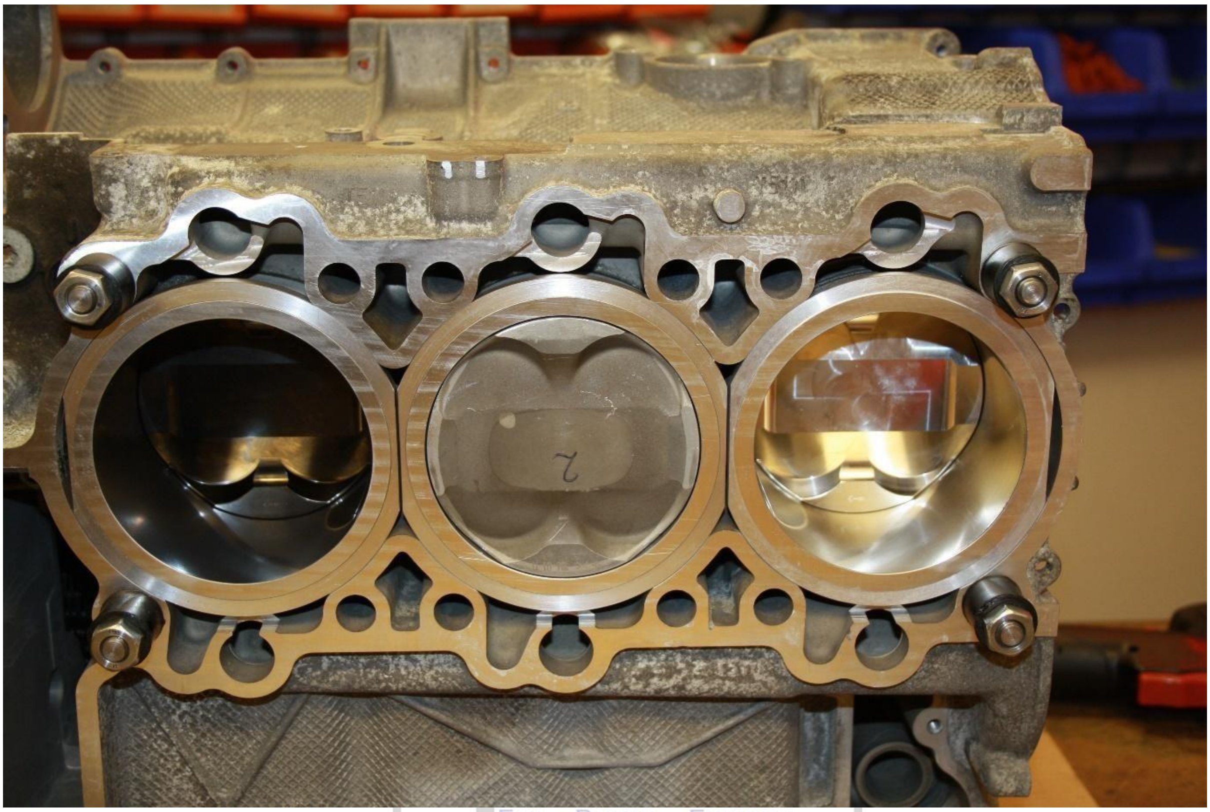
Before delving into bank 2 differences we did some research on piston coatings and discovered that pistons used in all previous Alusil engines (924S, 944, 968) and Lokasil engines (Boxster and early 3.4 996 models) also had hard ferrous coatings (called Ferrostan) – along with a copper initial electroplated coating and a final zinc flash).



We also found that due to some European health and safety legislation pistons could no longer being coated by the same process (which we believe involved cyanide) necessary for the hard ferrous coating and the new pistons from the new supplier had a screen printed “plastic metallic coating” instead (called Ferroprint).

Checking the original 944/968, Boxster S and early 996 3.4 pistons we confirmed that they did indeed have a ferrous coating (and would retain an attraction from a small magnet) and found that all the original manufacturers using Alusil hypereutectic cylinders had to be run with these hard iron coated pistons and the Lokasil (M96/7) engines did not score bores until the same hard coatings were replaced by plastic coatings.

Realising that a more reliable coating was needed for us to use our stock of rebore sized specially made pistons and for them to survive long enough, we tried to find an alternative to a hard iron coating that we could use and arranged to have samples coated by reputable alternative suppliers we could find Worldwide (including different materials both plastic and an alternative type of metallic coating) and to save testing costs fitted 2 of each in each of our test cars (one in each bank) to test 3 variants/test engine runs and 6 different coatings overall in 2 engines, as shown below.



Upon stripping and inspecting we found none were hard enough to last for an acceptable mileage. The best was a new metallic plated coating (ferrotec) from a major piston supplier but that didn't seem to be magnetic (which we think is probably the same coating used in the later 9A1 Gen 2 Alusil engines – but more about that later on).

Our research into the long term life of an Alusil block found that there was general acceptance reported that over many thousands of miles the silicon particles in the matrix would become loose and disappear to leave the bores smoother and with less silicon particles near the surface and therefore less spaces for hydrodynamic oil retention and this change in the bore surface finish was generally used to explain why after huge mileages they sometimes scored or seized.

It then occurred to us that a rather strange omission in thinking might have occurred because it had resulted in the previous researchers on the one hand accepting the gradual loss of silicon particles from the bore surface of Alusil but ignoring where they went or what damage they could cause and just concentrating on the surface remaining afterwards. We didn't find any

references to where they went, what would happen to them or what the result of that surface loss might be when the loose particles impacted on it. We also knew that because the silicon particles were evenly distributed – even if some particles became loose and disappeared – there would be new ones uncovered – so questioned if those original research conclusions were right or premature.

We thought that if hard pieces of silicon became loose as the aluminium substrate was gradually eroded (so they stuck out more) they are most likely to eventually be knocked loose by the passing of the rings on the surface and therefore the particles would become initially trapped under the ring and must slide up and down with the piston until presumably they would eventually be washed out with the oil and retained in the oil filter. Furthermore any loose particles would present a bigger hard surface to the piston than those mainly retained in the aluminium and the piston thrust loads would then be concentrated on the minute particle rather than spread over the piston thrust face and easily penetrate the oil film. This also made the need for a hard piston coating more understandable.

By now we had begun to think that it might be the hard silicon particles in both Alusil and Lokasil that were the cause of resulting bore damage (and not the bore surface left after the particles had disappeared) but we could not be sure if the damage they caused was from the piston rubbing against the particles while they are still a solid part of the cylinder wall or because the silicon particles became loose and floated between the piston and the cylinder surface which we wanted to investigate further to be sure. Because it took a long time before Lokasil engines scored bores (and the majority didn't score even after high mileages) we thought it was more likely that the damage was caused by particles loss and entrapment. We think this was the first time anything different had been considered linking the particles that everyone accepted do come free from the cylinder wall – to what damage they may do afterwards (as if they simply disappeared) and we found no evidence that anyone had considered that this could be the cause of lower mileage scoring.

The more we thought about the implications of this theory – it made more sense. For example it had become evident that once a piston and bore had scored, the engine could often run for 10 to 30K more miles before the oil consumption became too high or the knocking noise from piston slap became too loud. It occurred to us that IF (as many others claim) the initial scoring was caused by too much particle loss and too smooth a bore surface remaining (and too little oil retention surface spaces) – how come the engines continue to run while still applying thrust loads from the piston onto that claimed smoother cylinder surface for such higher mileages and very long periods.

Although the scoring is in vertical lines (that formed grooves that could support oil and eventually even provide a space for more loose silicon particles to slide into and away) there would be no significant area to support thrust loads (which need to be circumferential). So we realised that there must still be a remaining surface sufficiently suitable for hydrodynamic oil film strength after the initial scoring to continue to run this long and this of course would be the case if it was the particle loss that caused the initial scoring and not the retained cylinder surface.

We started looking for signs of particle damage on the pistons but they were so dull it was difficult to spot. But although we had not heard of anyone else using it for a piston coating - one of the alternative piston coatings we decided to try was DLC (an extremely hard shiny black diamond like material only 1 to 2 microns (or 0.00004” to 0.00008” – 0.001 to 0.002mm thick) and this looked different on strip down than all the other coatings that were always dull grey and didn’t show any particular scoring lines on the surface until a full failure occurred - as a result.

After running several thousand miles - in some places the surface of the DLC coated piston was still like new and extremely shiny (and therefore had never experienced any wear or metal to metal/silicon boundary contact with the cylinder bore) proving that the oil film was sufficiently thick (and/or strong) to keep the piston and bore apart under load) but in other places exhibited thin scratches that had penetrated the coating and were clearly visible (because they were shiny light coloured aluminium base alloy set against the dark shinny black DLC coating – something that we had not noticed when looking at the other dull coloured coatings).

If silicon particles on the cylinder wall caused the problem it would have quickly rubbed the very thin DLC coating away and/or turn the surface dull but the majority of the surface was totally unmarked whereas the scratches were in the general area that the piston was biggest and under load and we thought was therefore was more likely caused by loose particles entrapped between the two surfaces.

To be fair to others that have reached different conclusions - we are not so sure **we** would have understood this as quickly if we had not been able to see the evidence for ourselves through simply trying a DLC coated piston – but once we had, the evidence was clear and convincing. You can even see in the following photo - places where the score was initially quite deep and then probably because the particle changed in position to a smaller section – the scores reduced in depth.

We knew there were no bits of silicon sticking out from the cylinder bore after honing (because we have our own surface finish testing machine and electronic microscope and they were perfectly smooth before running). This helped us to believe that the hard silicon particles in the Lokasil must have become free from their matrix and floated free between the piston and the cylinder bore until the oil eventually washed them away or they stuck to the softer plastic coating in most of the pistons we tested and upon rubbing up and down the cylinder bore – created bore scoring. We were also surprised at the width of the scratches (that we were clearly seeing for the first time).

We figured that an analogy of this process might be similar to a newly resurfaced road which lasts perfectly well for a long period but that eventually releases a stone (especially in highly loaded areas) and that the loose stone then impacted on the other stones near the surface creating an ever lengthening pot hole in which increasing numbers of stones break even more loose (very similar to a bore score). The only difference with a road surface being that a loose stone then gets displaced but if a silicon particle stuck to the piston face it would run up and down with it releasing more and more particles (like a car being driven forward and backward over the same pot hole and pushing the loose stone to each end of the hole while it knocked more stones loose) creating a typical catastrophe theory failure – rapid and sudden.

Because there is always an oil film of some thickness between a piston and a cylinder bore - we also realised that the phenomenon would only occur (or occur first) on a cylinder face under the highest load and that once enough scoring had increased the clearances the piston could continue to run in the greater clearance the scoring created but that the rings would no longer seal as effectively and result in increased oil consumption.

These conclusions fitted the practical evidence perfectly.

We also realised that from simple basic theory – if a tiny piece of silicon was in the space between the piston and the cylinder wall then the unit load from the piston thousands of times higher than when the load was spread over the whole piston face and easily able to penetrate any oil film present and dig into anything soft enough like the piston – if the particles were big enough (something we needed to find out).

So we then researched what size these silicon particles could be to consider if that is similar to the size of the scoring marks on the DLC coated piston to assess what type of damage they could reasonably be expected to cause.

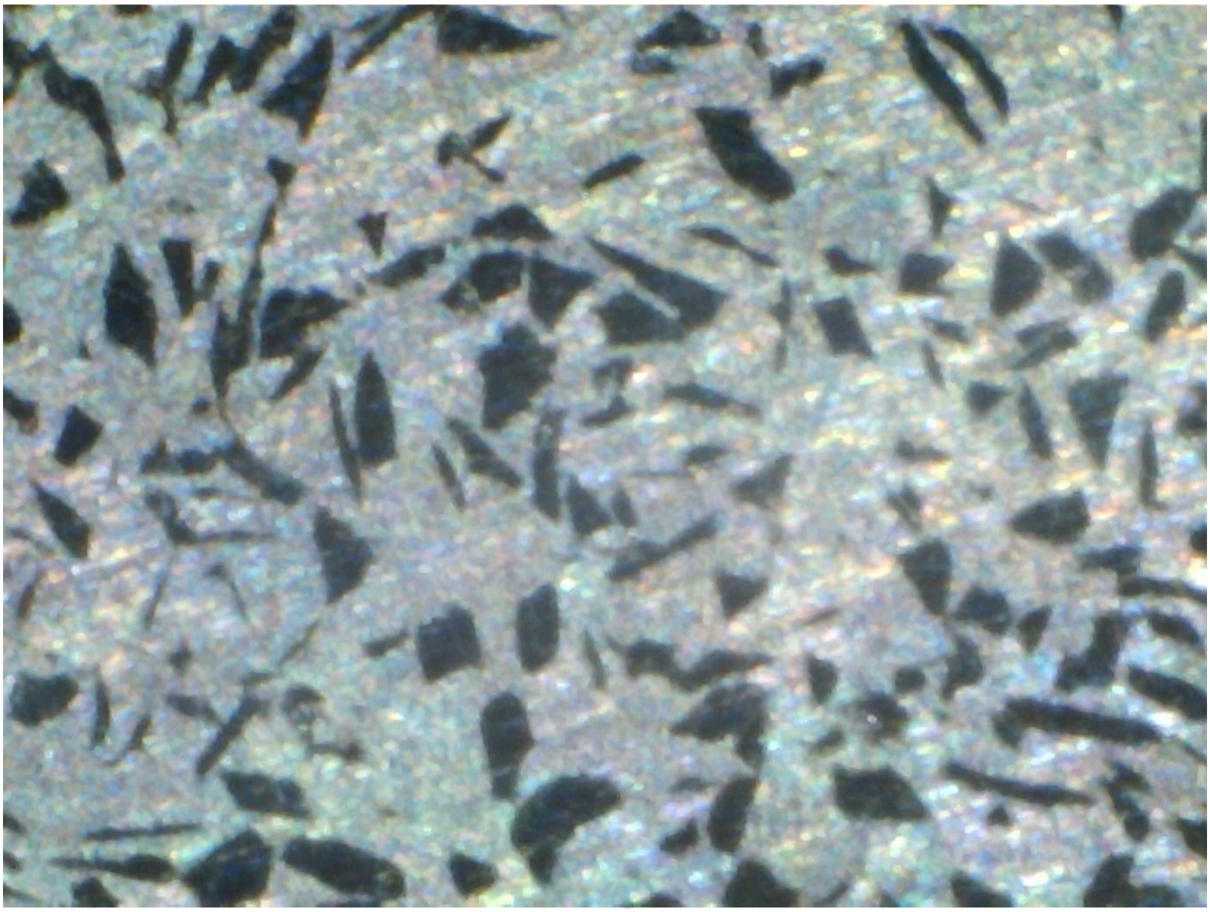
We were astonished to discover that in Alusil the **manufacturers themselves** reported that they were between 20 and 70 microns (0.0008 to 0.0028" or 0.02 to 0.07mm). This meant that although the particles in Alusil grow in the molten matrix (and were therefore extremely well bonded to it) if they did eventually become loose (as all the research accepts they do) they could be as big or bigger than the clearance between the piston and the cylinder wall and so would still cause damage (especially if the piston coating was not hard enough to resist it). We also found that the **manufacturers reported** that there were 2 versions of Lokasil described – Lokasil 1 and Lokasil 2. Lokasil 1 has silicon sizes of 30 to 70 microns (0.0012" and 0.0028" or 0.03 to 0.07mm) and Lokasil 2 is 30 to 120 microns (0.0012" to 0.0048" or 0.03 to 0.12mm) and 10% more particles by volume than Lokasil 1.

You will remember that after the 3.2 Boxster S, as the pistons increased in diameter, the cylinders became thinner (to leave enough space for coolant) and this resulted in them being weaker and becoming oval and eventually cracking. However upon measuring all the examples we strip for repair - we also found that later 3.4 to 3.8 engines did not stretch oval as quickly (despite being under even greater loads and just as thin) and we concluded from this that Lokasil 2 was probably used in the later engines (the Cayman S. 3.6 and 3.8 engines) since the bigger size and volume % of silicon particles would explain why the resulting matrix was stiffer and stretched oval less quickly in the same wall thickness of cylinder tube as the earlier versions.

However although most of the particles are probably smaller than the maximum size quoted - the biggest silicon sizes in both Alusil, Lokasil 1 and Lokasil 2 are confirmed to be similar to or larger than the piston clearance (and as there is an oil film present on both sides of the piston - that clearance would be less on each side) so if any large particles broke free from their matrix they could easily jam in between the piston and cylinder bore.
It is then crucial to understand that **IF** they did so the force from the piston face under load would not be spread over the whole piston face area but instead on a minute hard particle resulting in a massive load/unit area and certainly sufficient to penetrate the oil film, a softer piston coating and damage the cylinder bore – causing scoring. Whereas the original hard ferrouspiston coating

might not be penetrated a softer plastic one could be, and this difference might explain why the latter don't last as long.

The picture following shows the shapes of the silicon particles in Lokasil. It is not difficult to imagine that if these sharp edges (that might be as big or bigger than the bore clearance in their longest direction) came into contact with a relatively soft plastic coating – that it could damage it or wear it out.



We knew that Nikasil also incorporates silicon and Nickel and is electroplated in a matrix that forms a much more solid alloy so the incidences of particle release would be much less significant or frequent – but then found yet another reason why Nikasil is so much more reliable, long lasting and can run with completely uncoated pistons.

Our research found that the silicon sizes in **Nikasil are only 1-3 microns (0.00004" to 0.00012" or 0.001 to 0.003mm) - 1/20th the size of particles in Alusil or Lokasil** and anyway are electroplate bonded into a the Nickel material forming a much harder combination than silicon and aluminium – and thought this could also explain why Nikasil is so reliable and can even run directly on the soft aluminium of an uncoated piston as any loose particles could always be very much smaller than the oil film thickness keeping the piston and cylinder wall apart from each other. We then needed to research how thick a typical oil film might be between a piston and a cylinder wall to see if this explained how any large entrapped silicon particles could cause damage while particles 1/20th of that size would not.

Unfortunately most of the research we uncovered has been between piston rings and cylinder walls and the science and technology was largely beyond our ability to benefit from the terminology. However it was clear that the rings would cause the most wear (and be the source most likely to knock out silicon particles from the matrix).

But we didn't have the resources to test how the silicon particles became free from their matrix – was it rings, erosion or the hydrodynamic pressure of oil, or just fatigue – but regardless of the cause we were convinced that it was loose silicon particles causing the damage and therefore the clearances between the piston and the cylinder wall compared to the size of the particles was still relevant to our research.

In any case the research into oil film thickness was often conducted on non-firing engines, at low revs (under 2000 rpm) the best results being between 0.2microns and 8 microns (0.0000075" to 0.0003") which we found unhelpful.

So we used a different logic that if the silicon particle sizes in Nikasil were so small they never caused scoring (even on uncoated pistons) then the oil film thickness must be greater than that and this mean greater than 1/1000mm (0.00004"), whereas we knew the clearances of other bores being manufactured to have around 0.05mm to 0.075mm (0.002 to 0.003") but divided by 2 for each side of the piston face.

This meant we had an oil film space of between 0.0004" and 0.0001" (or if the piston was pushed against one side perhaps only 0.0003") and that the silicon sizes in Alusil and Lokasil can be as big or bigger than the clearance and therefore could indeed cause scoring whereas any loose Nikasil silicon particles would always be much smaller than the oil film and therefore just wash away with the oil.

This also clearly explained why you can run alloy pistons with no coating whatsoever in Nikasil (because even though any particle loss is extremely low in

Nikasil – the particle sizes will always be less than the oil film thickness and never penetrate the oil film thickens to become entrapped between the surfaces under load) but that is not the case with other silicon rich bore variants.
Wondering why it had taken us so long to come to this rather obvious conclusion we then had a “Eureka moment” - we finally realised that it was probably because it was wrong to describe Alusil AND Lokasil both as HYPEREUTECTIC alloys and that we had for too long assumed research and historical evidence of the performance of Alusil should be applied exactly the same to Lokasil. The very definition of “hypereutectic” relates to an excess of a secondary component emerging in an alloy on cooling – which Alusil is (remember it is a bigger solution of silicon in aluminium than the alloy can hold in its solution resulting in excess silicon particles growing into nodules evenly displaced around the matrix on cooling from molten). Lokasil is by contrast a collection of already solid silicon particles held in space by a binder forming a tube and later having molten aluminium squeeze forced into its spaces under high pressure (a process by which any volume or indeed size of silicon particles could be used).

Despite this the previous Alusil and these Lokasil bore engines worked very well as long as they ran in conjunction with hard iron coated pistons but the Health and Safety European legislation prevented the hard iron coating on the earlier pistons (that did not score bores) from being used on later pistons (that did) because the later plastic coating was insufficiently hard and/or well bonded to the piston face to resist the wear caused by hard silicon particles in the cylinder wall matrix. Lokasil proved to be less reliable than the true hypereutectic Alusil (that all the previous research was based on) and which too many specialists are using to try and understand the failings of Lokasil without appreciating the significant differences.

Although this mechanism of scoring now seemed convincing - it still didn’t explain why it only occurred on bank 2 first. Did it ever occur on bank 1? we wondered. Where to look for this anomaly would be significantly different if bank one eventually scored or never scored.

Fortunately a clue to that came several years later when some of our early customers (who had only authorised replacement of bank 2 Hartech cylinders and ran on with the original Lokasil cylinders running with our support rings on bank 1) eventually (as predicted to them by us) showed signs of bore scoring on bank 1 – so we reasonably concluded from the mileages they achieved that bank 1 seemed to last around twice as long before scoring occurred there as bank 2). This was extremely odd because there seemed no obvious reason why the release of particles didn't occur equally on both banks but for some reason scoring afflicted bank 2 long before bank 1. We needed to work out why the scoring afflicted bank 2 first to check if there was something else we had missed contradicting our conclusion – so we simultaneously researched how the different materials were manufactured and what any other differences were between bank 1 and 2 that might influence bank 2 scoring first.

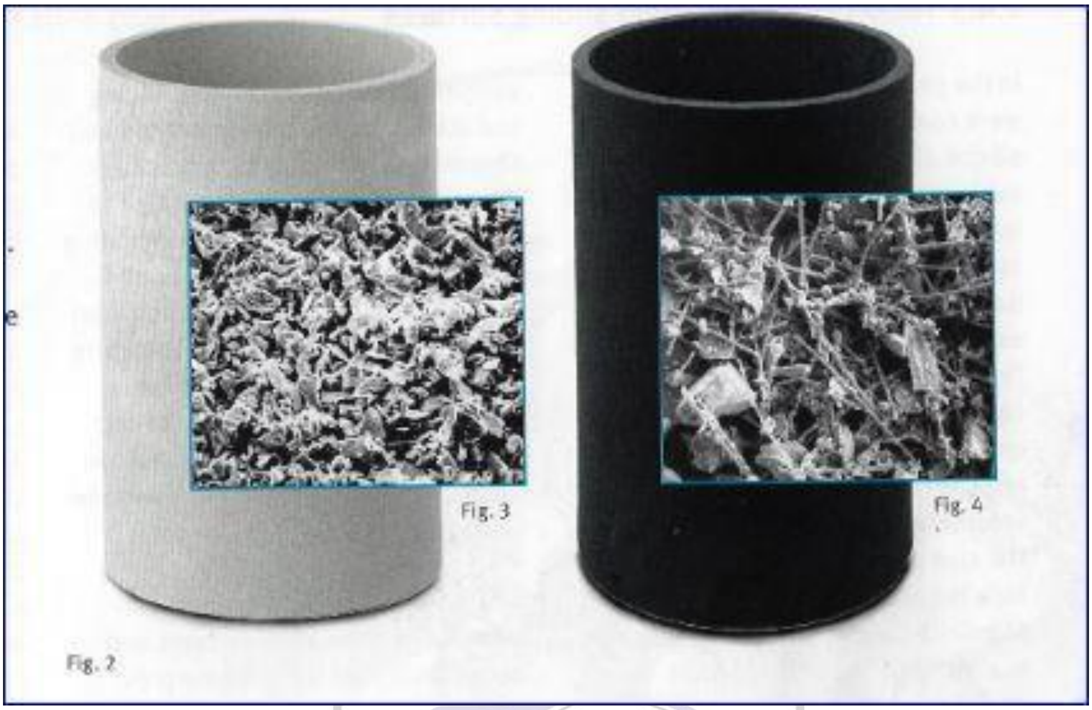
First - Material manufacturing research.

We found that Alusil is a true hypereutectic material in which molten aluminium mixed is with 17% silicon – but aluminium can only absorb 13 % silicon so the additional silicon material grows small but evenly distributed nodules of silicon which are strongly entrapped because they are formed from inside the molten matrix and should therefore have a slower particle release rate.

Lokasil is formed by a completely different process (although it was described in published information as having much the same outcome – which we now seriously question).

To end up with hard alloy containing silicon only near the cylinder bore surface - preformed tubes hold the silicon particles in tubes with an inorganic synthetic binder creating a very porous tube. The tube is then baked in a furnace (to burn of the resin bond holding the silicon particles in position) and fitted into the casting mould to be cast in.

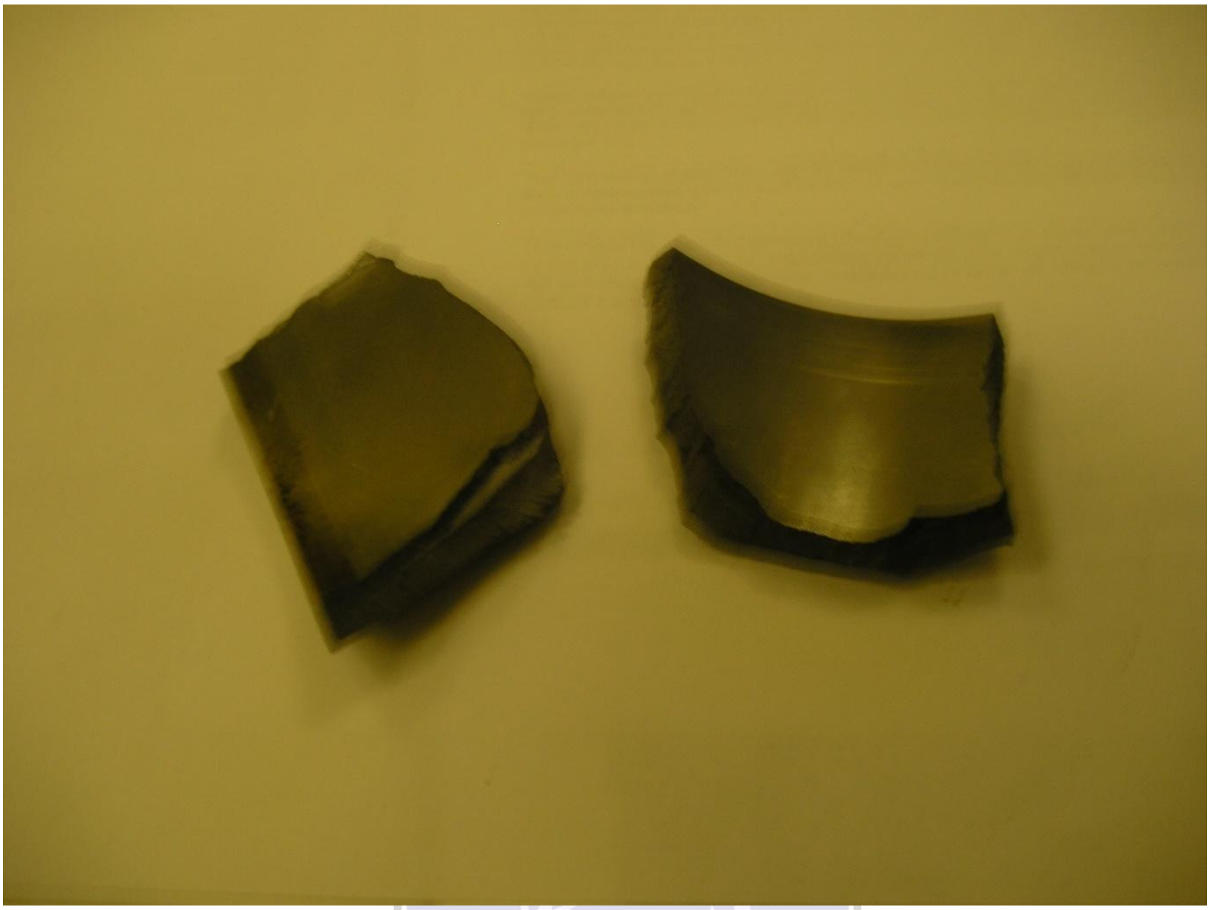
The following picture is of Lokasil 1 (LHS) and Lokasil 2 (RHS) preforms before the inorganic binder is burned off and before aluminium has penetrated the mixture and set with silicon particles entrapped near the bore surface.



The aluminium is then poured into the mould. It is not filled under high pressure while the aluminium flows in (as this could damage the fragile preform) but filled more slowly after which the mould is squeezed to increase the internal pressure by up to 1000 bar (or almost 15,000 psi) so that the molten aluminium flows into the porous pre-form entrapping the silicon particles only near the cylinder bore.

High pressure casting is a method of creating strong porosity free castings (because the pressure squeezes the air into minute spaces) but the entrapped air bubbles can cause issues long term in the future.

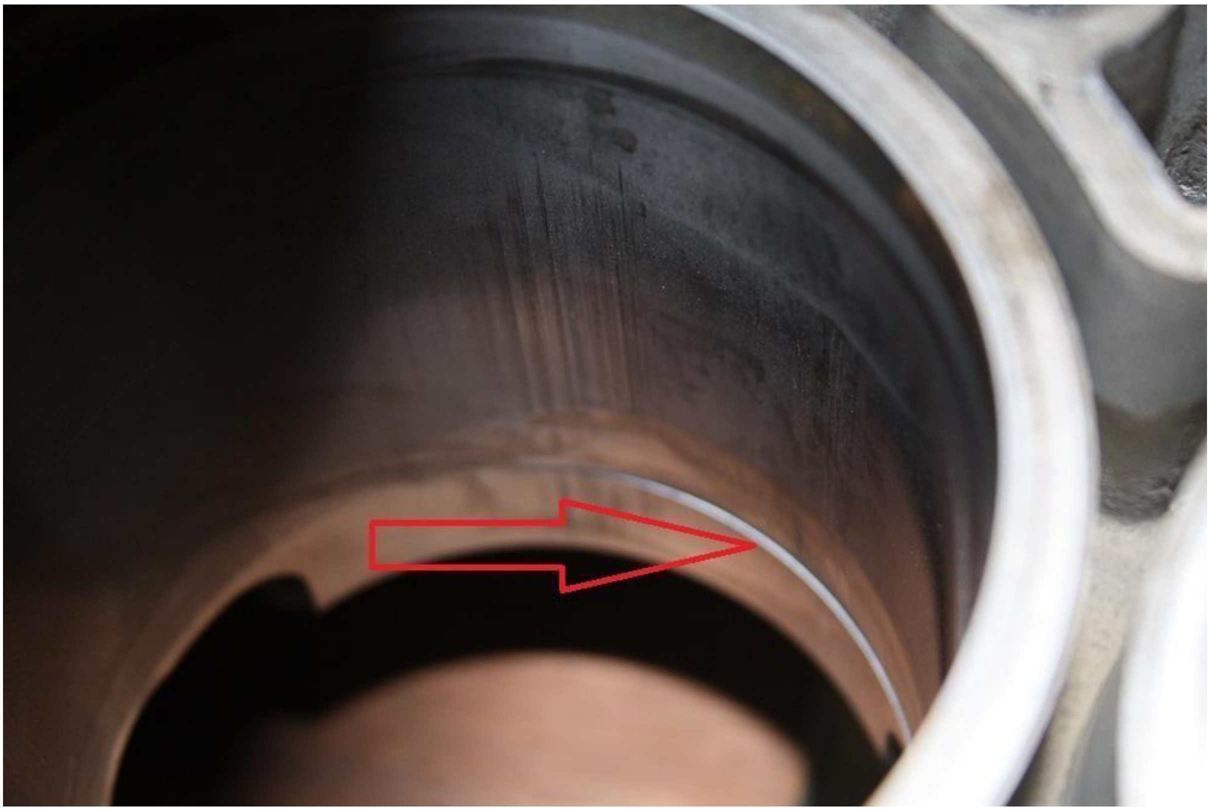
Squeeze casting is reported not to entrap air (as the molten alloy flows in without high pressure and only is squeezed once it is in position and the air is expelled). It therefore takes longer (and is more expensive).
Despite the manufacturers description it is clear from the result of looking at broken “D” chunk sections that the Lokasil portion is not as homogeneously cast in as you might expect and breaks showing a clear division between the two matrix’s.

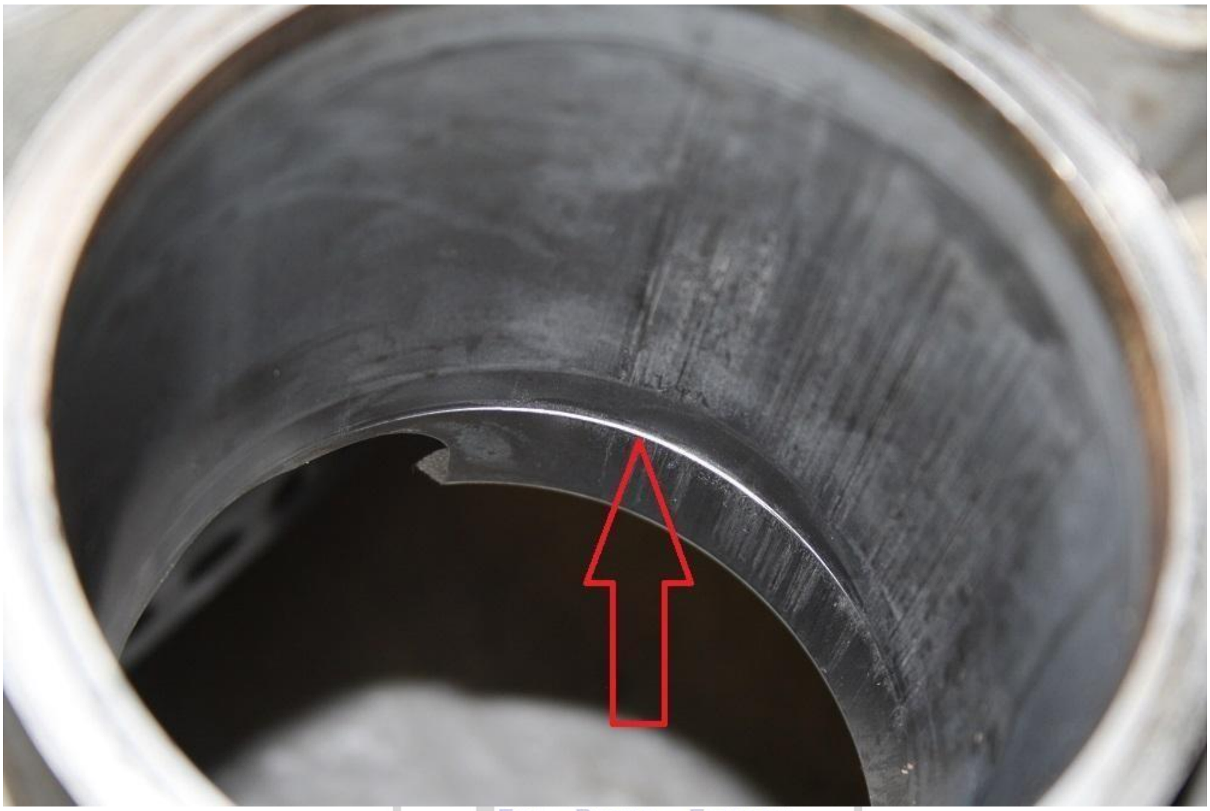


The enormous pressure necessary under squeeze - to enable the molten aluminium to flow between the porous spaces in the preform - now explains why the design of an open deck cylinder block was necessary since no sand cores would survive under such pressure and meant that things were starting to come together to explain the reasons behind them and that the design of the M96/7 crankcase with open deck cylinders was more of a necessity to be cast in metal moulds (to enable the molten aluminium to be cast under huge pressures to permeate the silicon preform) than for production speed.

However – we have a puzzle to uncover. Lokasil is promoted as being porous and we also found it both of less density than Alusil, or aluminium and silicon individually and easily crushable (which solid aluminium or Alusil is not) and so we think that after the squeeze process there must still be entrapped air spaces in the matrix which would therefore be small but under extreme entrapped pressure that could influence the bonding strength holding the silicon particles in place by either creating a thin barrier between the aluminium and the silicon particles or simply applying pressure to the inside of a silicon particle otherwise exposed to the cylinder bore. We had also stripped some engines in which the bore material had completely been washed away by oil or eroded to an unacceptable depth by the rings in some areas and many others where the distribution of silicon was not even and we thought this was similar to our analogy of a road surface that areas where too many stones were more densely distributed (and therefore with less tar between them) always seem to be the first to create pot holes.

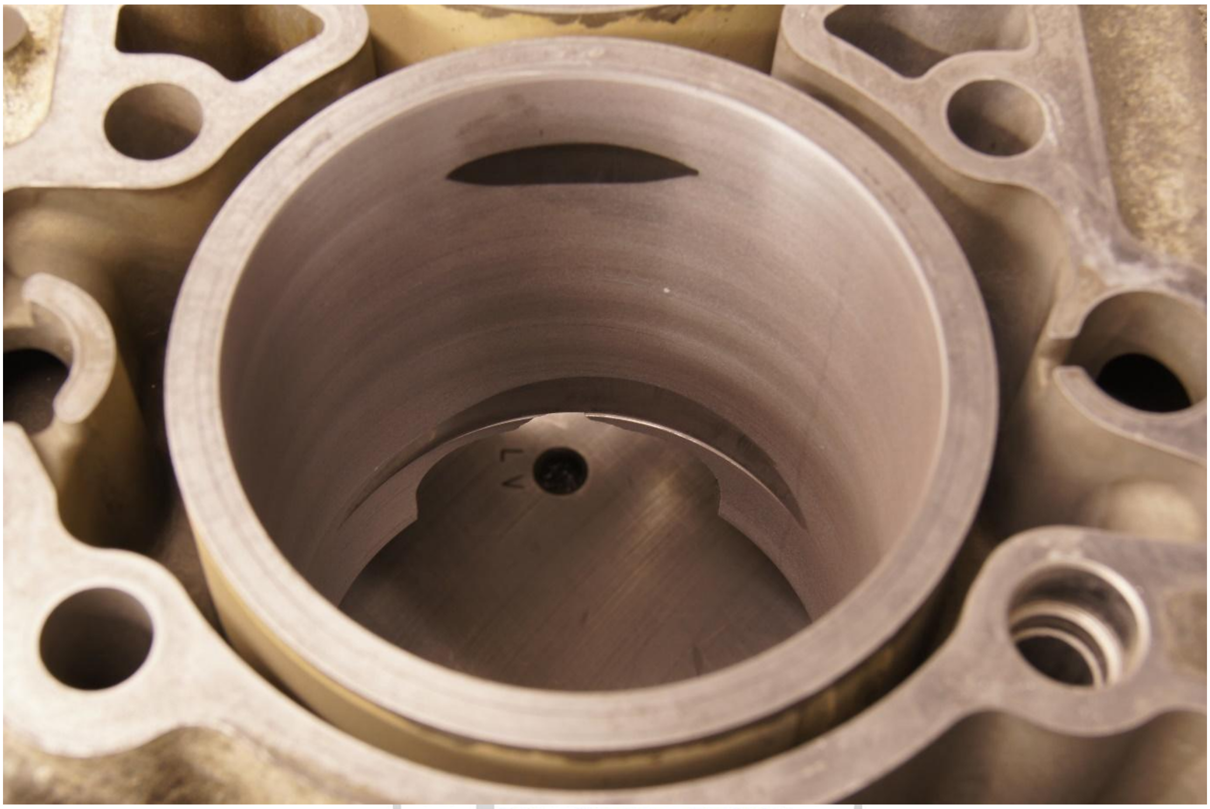
The following pictures show loss of silicon and alloy washed or scraped away by the rings and demonstrating the variation in the make up of the original preform before it was cast



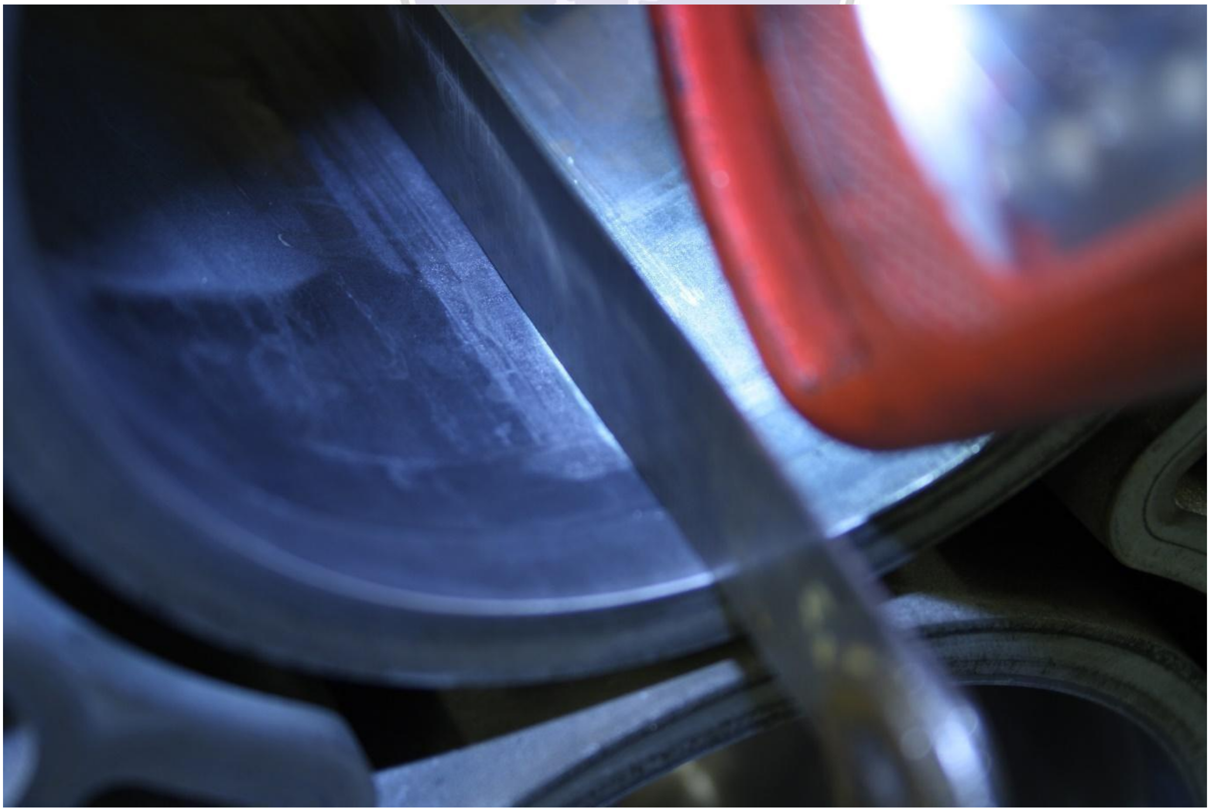


Despite already having machined away some of the original bore - this next picture shows areas not touched by the rings and clearly washed away.

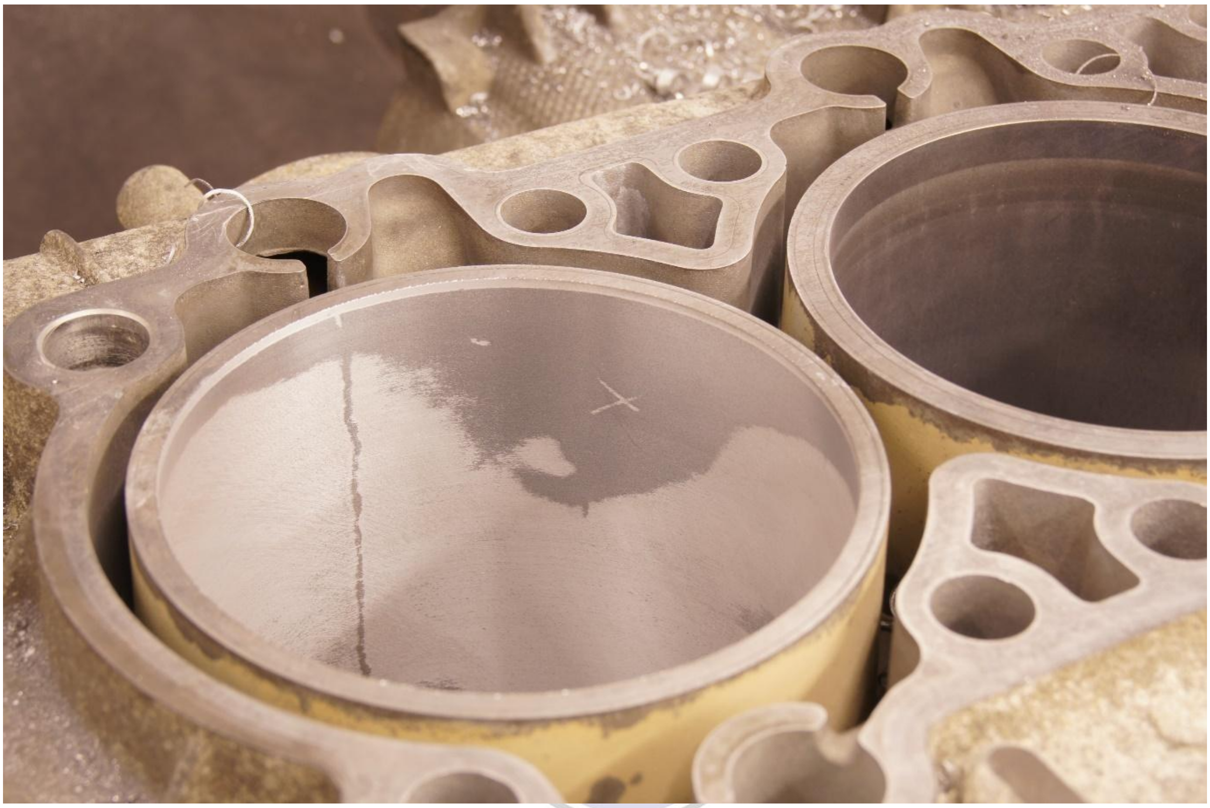
It also shows again the small standard slot that passes coolant into the cylinder block (on the RHS) and the main hole that delivers the majority of it directly into the cylinder head.



In the following picture the light is seen under a straight edge where considerable amounts of material have disappeared from the surface despite there being no actual bore scoring nearby. The shape of the missing material could not be caused by piston rings.



Another interesting observation was that as we machined away the Lokasil (to a point where it was microscopically thin) we saw a cross drawn on many of the preforms which were usually set away from the main thrust face and towards the sides (where there is no thrust load) and concluded that there may have been a selection process to place the observed best area of the preform (with the most suitable silicon distribution) to the thrust face (and therefore that the distribution of the silicon particles did indeed vary) and the rotational position of the preform was assembled in the casting moulds accordingly.



When machining out the original bore in steps we also noticed that the pre-form was not always round nor central in the block and understood there were clearly different qualities of positioning and silicon distribution in different areas of the block and that this could explain why some cylinders scored before others.

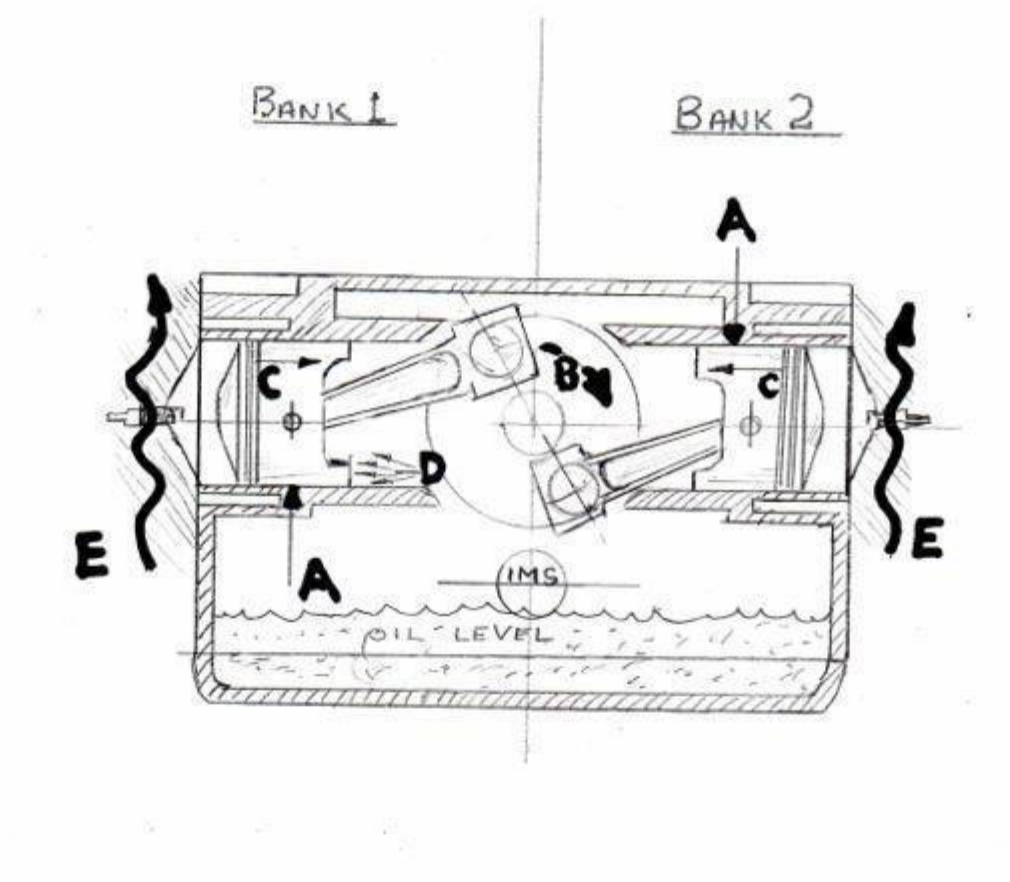
The pictures in the KS manual also show how honing would leave some silicon crystals embedded in the aluminium with a “dove-tail” shape (larger inside) that could lock them in place but others would be tapered so that the only bond stopping them falling out was the bond between the crystal and the originally molten aluminium – which may not be as strong as in Alusil where the particles grow within the molten matrix rather than have molten aluminium flow between them and up against them.

So - while we were by now convinced that it was free silicon particles that cause the damage - we were not sure what mechanism lead to earlier silicon particle release in Lokasil compared to Alusil. It could be less strong bonding than Alusil (which has good interfacial bonding by virtue of the way it grows in the molten matrix) , it could be more uneven distribution than Alusil, it could be aluminium oil wash eroding the depth between the silicon and the base material (exposing the particles more), it could be fatigue from piston ring interference knocking the particles free, it could be connected to highly compressed air pockets (resulting from squeeze casting) influencing the bonding or the bonded strength – or it could always be for some other reason we have not yet thought of. In any case it seems whatever the cause - that loose silicon particles caused the problem but analysing the manufacturing process threw no light on why bank 2 is affected first.

Second - Research to explain differences in both banks that would explain the concentration of early scoring in bank 2.

The scoring on bank 2 was always on the thrust side of the piston face (which is on the top of bank 2) but at much higher mileages eventually was on the thrust face as well on bank 1 (although this was underneath on the bottom of the piston).

The following sketch shows how the piston “C” pushed the crankshaft “B” round clockwise by pushing against the top of bank 2 “A on the RHS” and the bottom of bank 1 “A on the LHS”. It also shows where the spray jets “D” are both at the bottom and the coolant “E” enters the bottom of both cylinders and flows upwards.



We were by now confident of the above theory that loose particles of silicon were being trapped between the piston and the cylinder bore and only penetrated the piston coating surface on the side under load (that therefore squeezed the oil film thinner as the driver applied more throttle). That alone did not however explain why it was always only on bank 2.

While some competitors were publishing that the cause was fuel and/or injectors (without realising yet that it was only one side of the engine that suffered and therefore that was unlikely) we looked at any technical differences between bank 1 and 2 to see if that offered an explanation.

Bank 1 and 2 DIFFERENCES.

The thrust face (where the piston pushes hardest on the cylinder wall to rotate the crankshaft) is on the top of bank 2 and the bottom of bank 1.

There are oil spray jets (primarily to lubricate the little ends) are located on the bottom of both banks. So – because any oil sprayed out would fall under gravity (and therefore more could be falling on the bottom of bank 1 - the thrust face where they don't score and not on the top of bank 2 where they do) we tested if their volume and direction influenced scoring by fitting 2 additional spray jets directed to the top of a test engine to ensure bank 2 (which might receive less oil spray) was then adequately lubricated on the top as well. At this point the poor performance of the various plastic-coated special pistons we had tested helped us by using the least wear resistant ones to test and thus reducing the time, cost and mileages we needed to cover to visibly see and measure wear - revealing wear after about 5K miles but also confirming that the additional oil directed to the thrust face of bank 2 made absolutely no difference – so was not the cause.

It is also interesting to note that a lot of the specialist piston manufacturers used plastic coatings but made racing pistons. That is significant because racing engines rarely cover more than 1000 miles/racing season and this would mean that even in a Lokasil bore they could possibly last for a few years of racing mileages (especially as the revs in use would always be high and by which time they would be routinely replaced anyway) and could explain their initial confidence in their coatings in Lokasil.

We also realised long ago that another difference was that the coolant entered the bottom of the cylinders on both sides and exited at the top (see the sketch on page ***). We had also noticed that unlike most other previous engines - only about 10% of the coolant flowing was directed into the cylinder block. Racing 4 strokes had for some years split the coolant about 50/50 into the heads and cylinder blocks but this was much less than any other engines we have experience of – with the other 90% directed into the heads. To make things worse, as the engine capacities and cylinder tubes got bigger the exterior blocks remained almost the same size and shape and therefore as cylinder capacity and heat generated increased there was less and less coolant volume internally to keep the cylinders cool.

Theoretically the thermostat position also had an influence in some circumstances. Older engines usually placed the thermostat at the exit of the cylinder head and this meant that the cylinder head would always the hottest area but at the same temperature. If the weather was cooler then the radiators took more heat from the coolant and returned it cooler – and this made the thermostat close a little to restrict the flow and it was always the flow rate that kept one area of the engines at the thermostat temperature. But with the air also being cold, the slower coolant flow took even more heat out as the coolant flowed through the super cooled radiators so the thermostat closed even more and the flow rate was extremely slow as a result and delta T higher.

If it was hot the radiators had less cooling effect so the thermostat opened to increase flow and visa versa. When ambient conditions were cold the coolant was slower as it entered the cylinder block at a cooler temperature but took longer to pick up heat until it reached the exit thermostat – so the thermostat being at the cylinder head would result in the lower cylinder block running at different temperatures in different ambient conditions but the head at the control temperature would always be the same.

By moving the thermostat to the inlet of the engine it meant that this was where the temperature would always be the same – so as ambient conditions altered the flow rate it was the exit of the engine that would run at higher and lower temperatures and not the inlet.

So this would raise and lower the temperature of the coolant exiting the heads AND the cylinder block and in hotter ambient conditions the coolant flow rate would be higher and so the cylinder block would be cooler but in cold conditions it would run hotter – all as a result of the effect of the thermostat position on the coolant flow rate and the temperature rise through the engine.
So while some specialists proposed and fitted an additional radiator thinking it would help avoid scoring we understood that it actually added cooling and this in turn would make the thermostat slow down the coolant flow and increase the temperature rise within the engine, which would run the cylinder block hotter which in turn would make the oil hotter and thinner and this would mean that

any silicon particles that broke free and were trapped between the piston and the cylinder wall would impact more as a result of the thinner oil film.

Owners would probably not notice this affect because the coolant flowing into the blocks and the heads mixes together again before flowing out to the radiators (and because there was so little of it passing through the blocks compared to the heads any internal increase in the coolant temperature of the block would be disguised by mixing with so much more head coolant). With the flow in the cylinder blocks slow as a result we realised that the temperature of the cylinders would rise as the coolant absorbed heat while it passed slowly through the cylinder block and therefore that the top of the cylinders would always run hotter than the bottom.

This in turn would mean that the oil on top of the cylinders and pistons would be hotter (and therefore thinner) than that at the bottom and the oil film under load would be thinner at the top and thicker at the bottom.

This also meant that the thrust pressure from pistons on bank 2 could squeeze the oil film on the top thinner than the same load on bank 1 would on the bottom (due to the oil there being cooler and thicker there) and therefore if the silicon particle release was similar on both banks, the thicker oil film at the bottom of the thrust face on bank 1 would resist it damaging the piston for longer than the thinner oil film on the top of bank 2.

Right from 25 years earlier when we recommended using a thicker oil in the 944's (as the engines aged and clearances increased) we understood that time is the issue such that the longer a force is applied to an oil film – the thinner it would become – hence high torque, low revving applications would suffer more than at higher revs (when the load is applied for a shorter time) but unlike the 944 (where the thrust loads and temperatures were the same on all cylinders) we realised that the difference in thrust faces compared to the inlet position of cooler coolant was probably significant.

So to test our theory out we fitted temperature sensors inside the cylinder blocks (to both banks) and this confirmed the temperature differences we had theorised about.

We also realised that a hot engine when temporarily static (engine stopped or on tickover) would have hardly any coolant flow in both banks and that the top of the piston on bank 1 and 2 would experience thinner oil there and reduce the clearances when the car drove off – increasing the damage potential of any loose silicon particles. This would result in cars used rarely probably scoring sooner than those used daily (which seems to be an established correlation).

We had also noticed that we received a higher proportion of Tiptronic scored bores than there were tiptronic cars sold and were able to link and explain this because tiptronics usually set-off in 2nd gear with increased torque at low revs and therefore higher piston/cylinder loads resulting in even thinner oil film thicknesses.

We also researched any other examples of similar bore scoring.

The results were that they occurred elsewhere more often at lower revs and higher loaded conditions with bigger pistons (motorcycle engines with big bores and large diesels) usually referred to as scuffing instead of scoring - and this also seemed to confirm our theory since at low revs there is more time for the thrust load to squeeze out the oil film thinner and thin enough to allow any loose silicon particles present to impact on the piston coating more (or in cast iron liner'd large diesels simply squeeze all the oil out and be running metal to metal).

There is also the potential minor damage that could occur on starting the engine after the oil has drained off the top of pistons from both banks (and until the oil splash coats the bores). Gravity results in this oil pooling at the bottom of both banks which is the thrust face on bank one (leaving the thrust face of bank 2 drier) – so there may be a stroke or two during which Boundary conditions are in effect and the initial firing piston rubs against minimal oil on its bank 2 thrust face while pistons on bank 1 will be resting in a thicker oil film resulting from the hot oil dripping down to the bottom under gravity after the engine was shut off and cooling into a thicker viscosity and staying there.

Although this difference in the temperature was small – so it was also in the 944

S2 and 968 engines that similarly suffered bore scoring when the head gasket perished and increased the temperature of the rear cylinders (the ones that always scored) compared to the front ones.

This picture of different replacement Hartech liners/cylinders shows up some of those differences with the LHS picture being a replacement cylinder for a 944 turbo, the centre one being for a 9A1 Gen 2 engine and the RHS being a liner for an M96/6 engine demonstrating both how shallow the coolant depth is (the ribbed areas) and how Porsche reverted to the original Alusil 944 coolant depth in the newer 9A1 Gen 2 engines after the problems with the M996/7 engines.

We thought it was entirely reasonable that as bigger engines came on stream and piston loads increased while coolant volumes decreased, in a cylinder block already running with minimal coolant – that these small variations in temperatures (and their resulting influence on the oil film thickness) could – over a period of time – impact on bank 2 before bank 1 – as a result of pushing the boundary of reliability a step too far without upgrading the cooling system to cope.

While all this research and testing was going on we also puzzled how on earth Alusil and Lokasil could ever work if the largest particle sizes that might be released could be bigger than the bore clearances. That is until we realised that they are very irregular shapes and so would only be at the maximum size reported in one direction and it would be more likely that when they became detached from the cylinder wall that they would sit between the piston and cylinder wall in one of the thinner dimensions and anyway most of the particles would be smaller (and the ones near the surface might already have been honed smaller before releasing into the engine). This would make the incidence of the size of the particle release being significant - occuring later on at higher mileages – which also fitted the evidence.

Also – we must not forget that there is only one very small part of a piston surface (in the centre) that you measure for piston clearance - everywhere else the piston is tapered, barrel shaped, oval - and the top where the rings are is very much smaller – so the piston runs with much more piston clearances on most of the surfaces (where clearances are perfectly adequate to allow the size of any loose silicon particles to exist in-between the oil film present and float away in the oil film) except for a small patch in the centre of the piston face about half way down where the biggest diameter can be measured (which also happens to be where the maximum thrust is applied under load **and where ALL the initial scoring occurs**).

You can see from the following pictures of early marked pistons that the damage is indeed right in the centre where the clearance is smallest and visual inspection shows that it would take a particle to do this damage and not a smooth bore suffering from inadequate hydrodynamic oil film.

Once the centre coating has been picked off or worn down – the ovality reduces and the contact patch spreads further round the circumference so the positions each side of the centre would then be the next to be closest to the cylinder wall and so the wear would gradually spread around the thrust face of the piston until there was little or no coating left to try and resist the impact of a large piece of released silicon (and this was evident on stripping and inspecting hundreds of pistons).

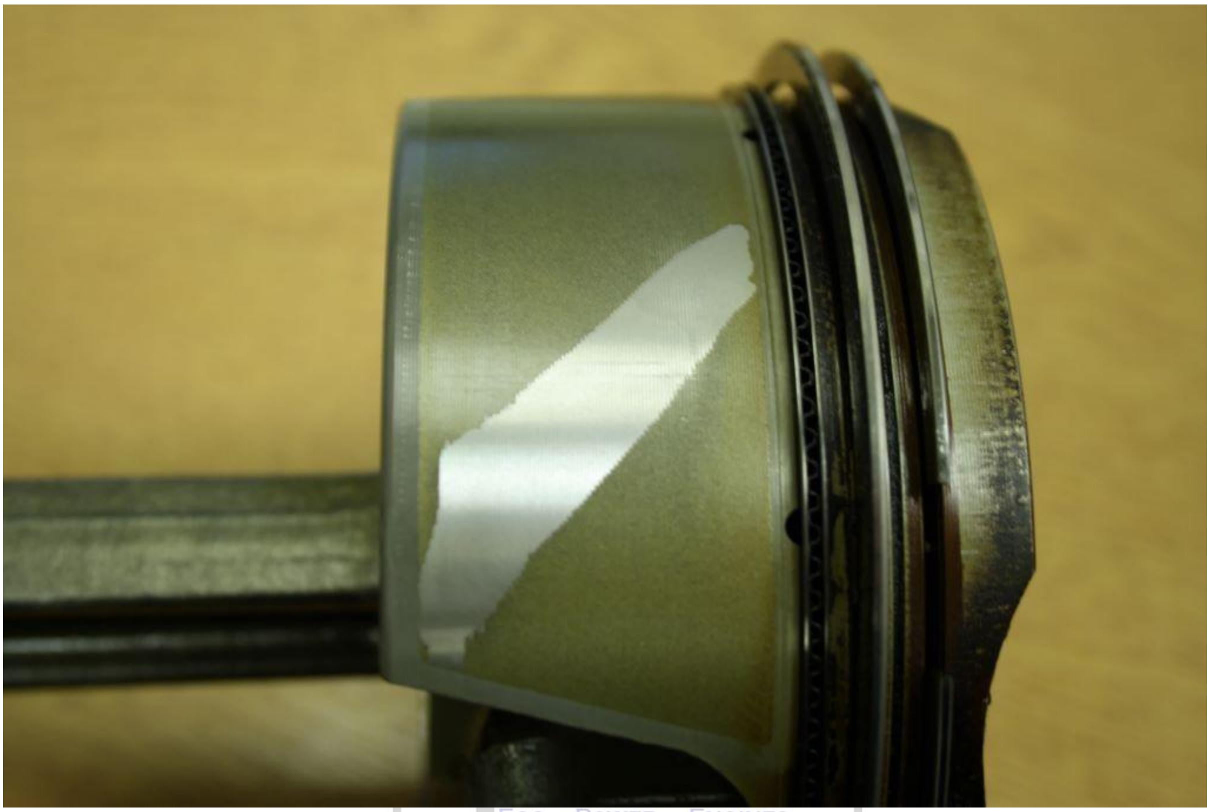
We also knew that pistons are designed to (and expected to) deform under loads such that the thrust faces actually bend very slightly inwards under load and flex back out again afterwards and this also helps explain why it takes a long time for any large silicon particles to penetrate the piston face when they are released where the piston is biggest and lasted longer on hard coated pistons.

Over many years stripping damaged engines we were probably able to observe more varying piston conditions than most of our competitors and from this we found the plastic coatings on some pistons had gradually worn too thin, on others had fallen off in patches and in some was still there but had become de-bonded from the piston and were only there by virtue of its connection to nearby coating that it was still bonded to and that the plastics used have much reduced hardness as they heat up (which the original ferrous coatings never experienced).

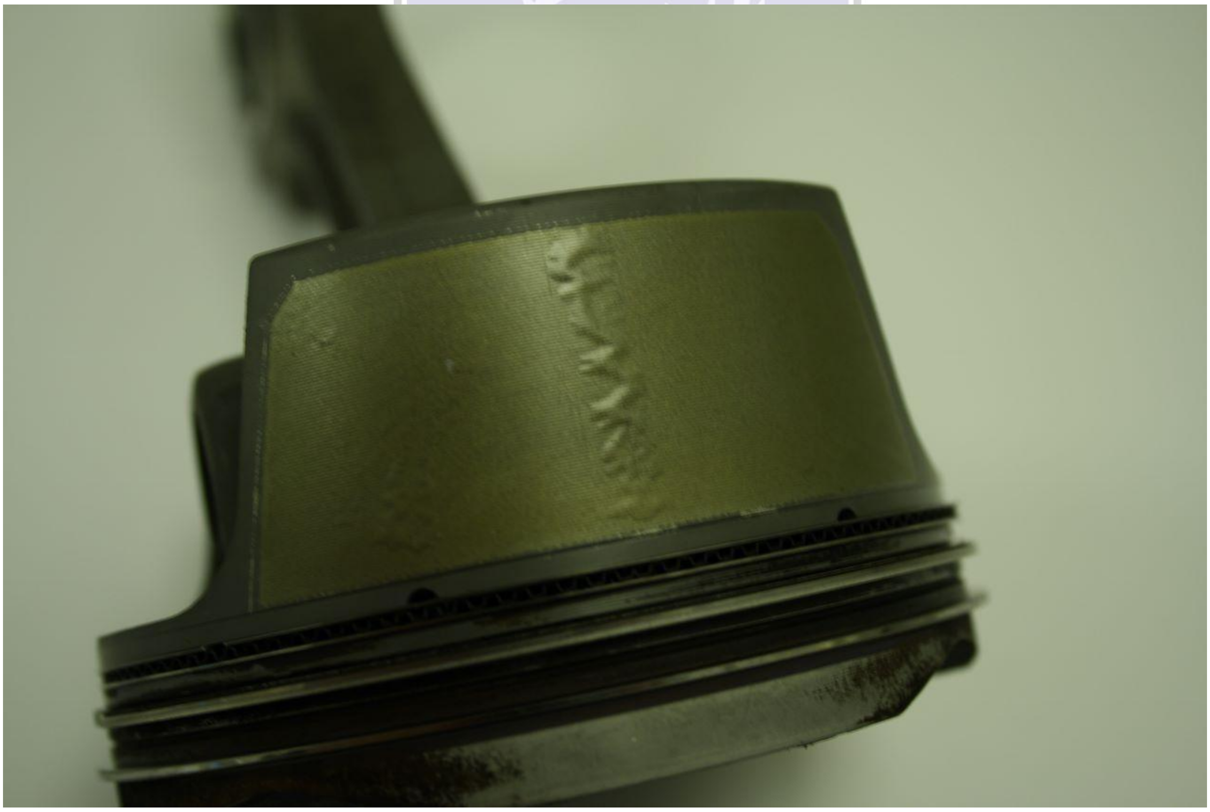
The following picture shows how loose silicon particles have gradually plucked out pieces of plastic coating moving to each side of the centre of the piston. If it was the surface of the bore that caused the problems it would be expected to result in a smooth wear pattern all over the thrust face and not patches as observed.

The next photo shows how sometimes we find a whole area has just completely flaked off leaving the original piston surface shiny (as it was when it was originally machined) before wear against the cylinder wall would dull the surface.

And this photo shows that bonding strength of the plastic coating to the piston face must also be an issue to enable a diagonal strip that will have been plucked in the centre first - to come off diagonally when all the motion is only vertical.



Perhaps the most revealing photo (which we luckily managed to obtain just before the coating was torn off) follows.



This shows bubbling of the coating away from the alloy piston surface yet still intact with the remaining screen-printed coating. If it was the case that it was gradual smoothing of the cylinder wall that reduces the hydrodynamic oil film and causes scoring – we feel that the surface would then have worn into the bubbled coating and be visually obvious. But because it was still in tact – we feel that it was just waiting for a loose piece of silicon to dig into it and pluck it away, leaving a patch of bare aluminium (as observed in most examples).

It is only when someone strips and rebuilds such a huge number of engines (as we do) that fate steps in and overall provides such a large range of failures that it is possible to correlate the causes and find just one explanation for them all (as we eventually have in this case). Even after seeing so many failure it still took a very long time to put it all together and find the correct explanation to it all. We think it may have been the smaller numbers that others may see (combined with them placing too much reliance on Lokasil and Alusil being the same in practice – just as we did initially) - that explains how so many other specialists have come to different conclusions about the causes of bore scoring and attributed them to issues that our research frankly disproves.

This remarkably lucky picture of just one piston with this bubbling (at the time but now repeated a few times since) proved that as long as the oil film is present (and is sufficiently thick) it reduces the friction between the piston and the bore (even under power) enough (in some circumstances) to allow the plastic coating to remain in place even when it is no longer bonded to the piston.

Referring back to the pictures of silicon particles entrapped in the alloy bore matrix – it is now easy to visualise how just one of those sharp and unevenly shaped particles that became free would pluck at the bubbled are and that a whole large piece (or pieces) of coating would then come away (and probably end up in the oil filter). Our bubbled coating picture was possibly just waiting for the next loose particle to resulting coating loss patches.

It is also very difficult to imagine that in circumstances like this – any type of oil would be able to sustain an oil film between the piston coating when a sharp piece of silicon (as big or perhaps even slightly bigger than the piston clearance) floats between them (and remembering the results of load over area taking all the thrust loads over a minute area) which would then easily penetrate the film and damage the coating and/or remaining silicon particles that it then comes into contact with before escaping into the oil sump. Indeed this whole research project showed up different failure causes between badly coated pistons just allowing whole areas of coating to peel off, other alternatives where the coating bubbled away from the piston first and some others in which the coating remained well bonded but was generally worn away over a long period of time by slowly released silicon particles.

With the variation in silicon distribution and the changes in particle sizes combined with the realisation that all running materials wear and release particles over time and that hypereutectic Alusil (and Lokasil) cylinders release relatively large silicon particles (hence the original need for the hard plated piston surfaces), the reduced wear rates of the new soften piston coatings (especially when they are hot) and the differences in the temperature of the coolant and oil (and the consequential reduction in oil film thickness on bank 2 cylinder top resulting in the pinch on and damage from released silicon particles being greater on that bank) – we now had an explanation that fitted all the technical research, practical observations and experiences reported Worldwide and confirmation of why our Nikasil plated alloy cylinders completely eliminated the issue.

The level of research we have carried out to understand this and other problems has been extensive and well beyond what would be reasonably expected of such a small independent business. We had to buy several different models for test, buy machinery to manufacture different components, buy special pistons with different coatings, fit them to test engines, drive them for thousands of miles, strip, measure and inspect the internals, analyse the results (often rebuilding again with changes and different parts and settings to repeat the whole process over and over again) and compare the results to the evidence of failures, the manufacturing processes involved and reports and conclusions from other specialists Worldwide involving the main 3 different failures.

The huge overall cost of this programme exceeds any potential for recovery under normal trading circumstances but was supported under our government's research and development programme without which it would not have been possible to justify or afford.

For over 15 years we have stripped and seen all the different failures and competitors rebuild options and during this period we have rebuilt over a thousand engines and fitted several thousand alloy liners and IMS replacements without failure and experienced the success of our more reliable rebuilds than anyone else. We also have the evidence of failed solutions posted on Internet sites elsewhere relating to the problems that are the subject of this report.

We therefore now question the claim that silicon particle release results in the cylinder bore becoming too smooth to provide enough valleys for hydrodynamic oil film retention. We think this is possible in Alusil after huge mileages – but all our tests with soft piston coatings resulted in the same cylinder and piston scoring long before surface wear had taken place (but not before loose particles were released from it).

Some reports suggest that a contributory factor is the rod to stroke ratio. Although there is some disagreement about the ideal ratios most seem to accept that something near 1.7 is good. Here is a chart of those ratios.

Column1	Column2	Column3	142	rod	ratio
TYPE	Bore	Stroke	Capacity	length	Ratio
Boxster 2.5	85.5	72	2481	145	2.01
Boxster 2.7	85.5	78	2687	145	1.86
Boxster S 3.2	93	78	3179	145	1.86
Hartech Boxster S 3.2 to 3.7	100	78	3676	145	1.86
996 3.4	96	78	3388	145	1.86
Hartech 996 3.4 to 3.7	100	78	3676	145	1.86
Cayman S 3.4	96	78	3388	145	1.86
Hartech Cayman S 3.4 to 3.9	100	82.8	3902	142	1.71
996/7 3.6	96	82.8	3596	142	1.71
Hartech 996/7 3.6 to 3.9	100	82.8	3902	142	1.71
997 3.8	99	82.8	3825	142	1.71
Hartech 997 3.8 to 3.9	100	82.8	3902	142	1.71
997 Gen 2 3.6	97	81.5	3614	140	1.72

Hartech 997 Gen 2 3.6 to 4.0	102	81.5	3996	137.31	1.68
997 Gen 2 3.8	102	77.5	3800	140	1.81
Hartech 997 Gen 2 3.8 to 4.0	102	81.5	3996	137.55	1.69

You will see from this that the worst examples for scoring actually have the best rod to stroke ratio making the original suggestions that they contribute to scoring above unlikely.

Another contributory factor that has been proposed is the offset of the gudgeon pin to the centre of the bore (without realising that up and including 996 3.4, one bank of the engine had the offset the right way round and the other the wrong way round, that the later versions had them the correct way in both banks and the 9A1 reverted to one bank right and one bank wrong and there is no correlation to those differences and bore scoring or seizing.

Despite reading extensively the different opinions that exist on the Internet we have not found any others that fit all the evidence AND all the technical analysis and therefore they do not combine all our research (like we have) to fit our solutions in every case and in every aspect nor that have been the subject of such continuous, widely spread, tested nor as deeply researched analysis or vehicle testing - and as a result we believe our conclusions are presently the most reliable.

Conclusion.

Predicting lifespan before scoring is impossible.

Engines with excellent silicon particle distribution, excellent well and evenly bonded piston coating, that were warmed up before driving hard, driven often (to maintain some oil on the top of the bank 2 piston face) that had a low temperature thermostat fitted and a thicker oil as they aged (and increased mileages) with sensible owners throughout that avoid driving hard when hot after a period of rest and generally cover long journeys when in use – may well experience over 200K before scoring a bore.

Engines with poor silicon particle distribution, original thermostat, thin oils, driven hard (or revved high) from start up and poor piston coating bonding that experience a lot of short journeys may well score after 15K.
In between these higher and lower limits, it is impossible to tell without knowing all of the parameters that applied including the condition of the inside of the engine bores and piston coatings that can only be assessed on strip down (when it is probably too late).

Engines susceptible are Cayman S 3.4, 3.6 and 3.8 engines (which as well as rebuilding standard capacity we also offer a 3.9 conversion for).

Some specialists still insist that scoring is all to do with the smoothness of the cylinder wall after the silicon particles (which they admit escape) have disappeared. If this was the case how does that answer the following questions.

(a) Why then did harder coated pistons survive with no bore scoring in Lokasil cylinders since the smoothness they rely on would result in loss of hydrodynamic oil film pressure just the same?
(b) Why does bank 2 score long before bank 1 when general wear on both banks would be the same?
(c) What caused the scoring marks on our otherwise smooth and shiny DLC coated pistons?
(d) How would the bubbled coating stay in tact against the cylinder wall but then suddenly be plucked off unless by a piece of free silicon?
(e) Why did KS (who stated Lokasil will only work with a hard iron coated piston) stop supplying them when the coating method was banned?
(f) What caused the loss of sections of bores deeper than others (pictured) unless the Lokasil silicon distribution varied?
(g) Why did some pre-forms have marks locating them away from the thrust face if there was not a variability of silicon distribution in the pre-form?
(h) Why did Porsche revert to Alusil (and a harder piston coating) for the 9A1 engines?
(i) Why did Porsche reduce the clearances of the thrust faces of the 9A1 Gen 2 engine unless they were trying to spread the load/unit area because their new coating was not as good as the original banned one?

(j) Why can Nikasil run with completely uncoated pistons even when it becomes smoother?
(k) What happens to the silicon particles that are by the manufacturers own admission potentially larger than the piston clearance after they are released?
(l) Why would those particles not impinge on the piston and cylinder bore through the oil film when the load/unit area would then be thousands of times higher while they were entrapped?
(m) How would any oil resist the penetrating forces of a hard piece of silicon larger than the gap between the piston and the cylinder bore?
(n) Why did Porsche return to Alusil and combine it with a harder plated piston surface coating if the softer plastic coating were not a contributory factor.

All the above questions are answered by our submission that more damage occurs earlier as a result of greater silicon particle loss in Lokasil than Alusil and that the later -plastic piston coatings will not resist the resulting wear for as long.

We not only replace scored cylinders with our Alloy nikasil ones but also provide oversized versions converting the 3.4 Cayman S, 3.6 and 3.8 to 3.9 litres.

(4) **Cylinder scoring and seizing Gen 2 9A1 engines**.

This is a much more infrequent occurrence than the above M96/7 scoring and not yet causing major concerns over numbers and general reliability.

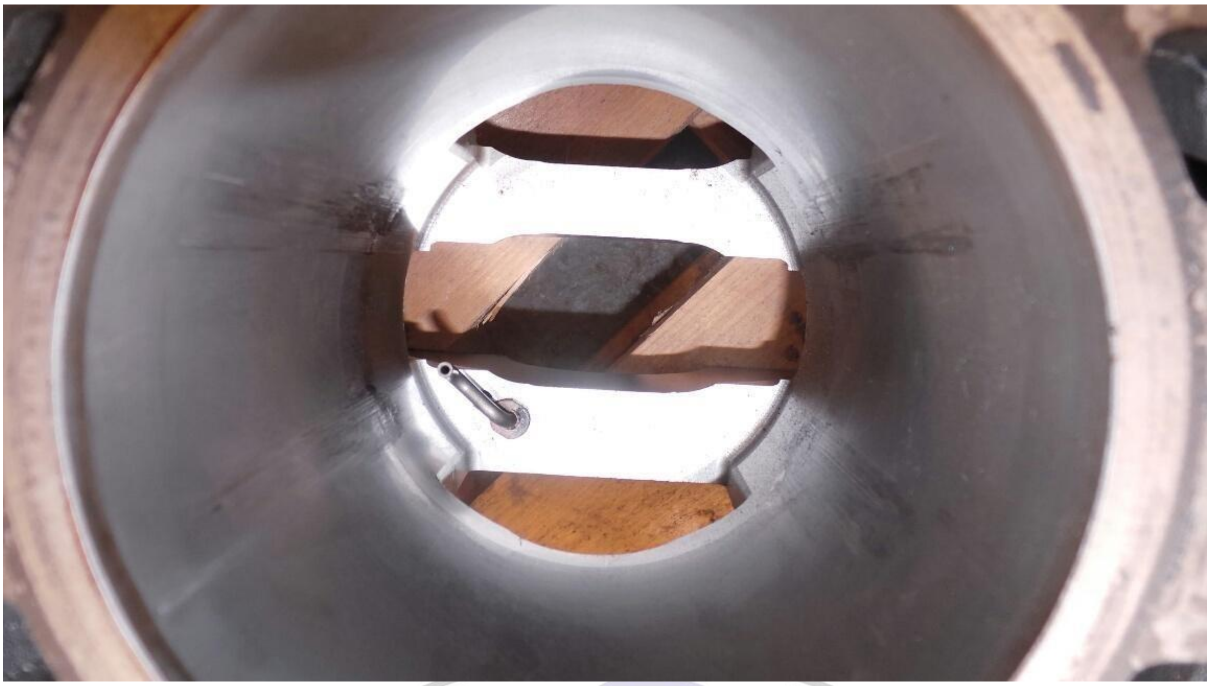
There is a difference between cylinder scoring (sometimes referred to as scuffing) and seizing.

Scoring is what we refer to when one side of the piston and cylinder bore are damaged but the other side is still unmarked. It is caused by something either wearing away the piston coating on the thrust side of the piston (especially on the side of the engine where the thrust side is hottest) or small silicon particles getting entrapped between the piston and the cylinder wall that the forces pushing the piston face against the cylinder wall are sufficient to overcome the oil film thickness and therefore result in rubbing against the piston and cylinder surface in Boundary conditions. The harder the piston coating and the better the particles are bonded into the cylinder wall matrix – the longer time will pass before this creates a scoring problem. Anything that results in the piston or cylinder running hotter than it was designed to will make the oil thinner and reduce the thickness of the resulting oil film bringing the piston face closer to the cylinder wall under load and entrapping particles that might otherwise float out within the oil film thickness causing no damage.

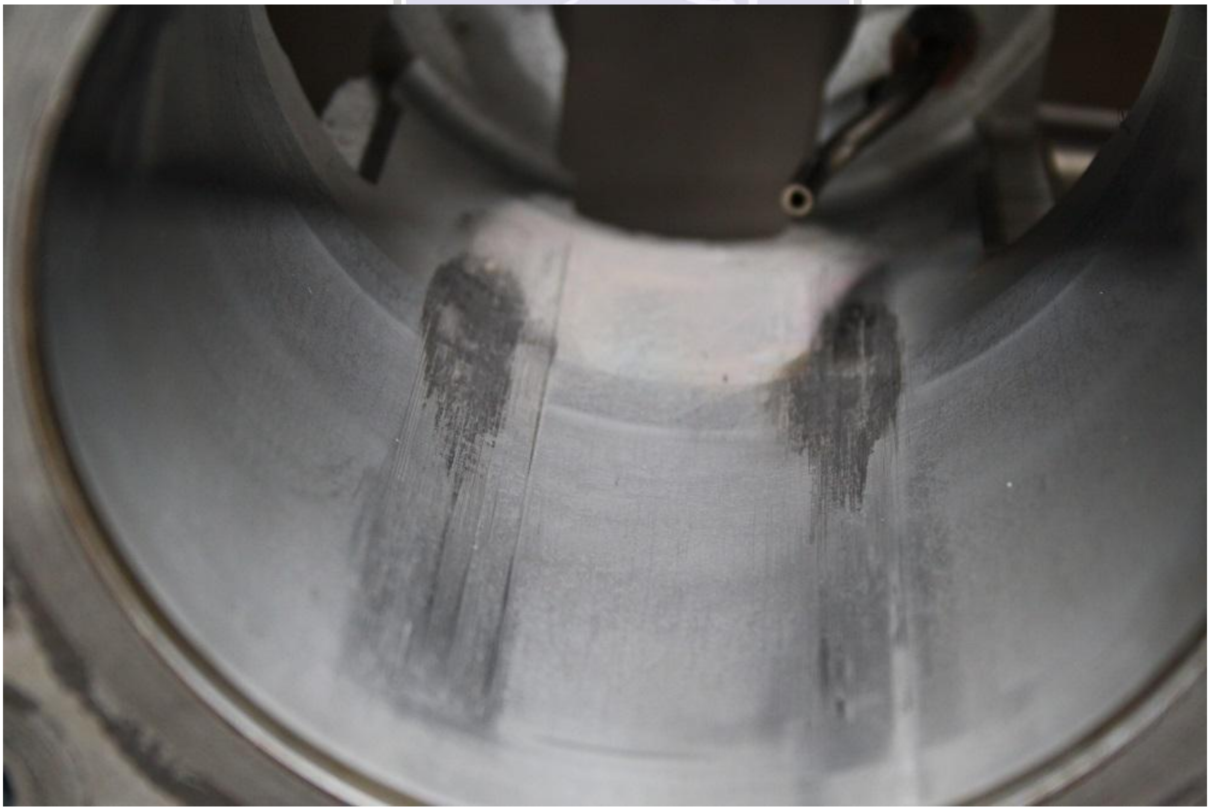
The 2 principle causes of this type of failure are – (a) anything that makes the piston run hotter than it was designed to do – resulting in it reducing the oil film thickness (weak mixtures, faulty injectors, too advanced ignition, higher coolant temperatures, loss of coolant etc) and (b) anything in the original casting that results in the more frequent release of silicon wear particles in a particular engine or cylinder.

Seizing occurs when the piston has expanded more than the cylinder it is fitted into so that the forces pushing the piston faces against the cylinder wall exceed the ability of the oil to keep them apart and the heat generated from the increased friction loads results in micro- melting and welding of aluminium particles on the piston face that then rub deep grooves in the cylinder wall. This then causes more cylinder wall material to be scratched out creating a rapidly failing sequence sometimes resulting in the piston being jammed in the bore and at other times still free but with the piston badly damaged – often crushing the piston faces inwards which increases the original clearances and sometimes leaves the engine running but badly damaged.

The following picture is looking down a Gen 2 bore and shows the seizure marks on both sides of the bore (and coincidentally very much nearer the bottom where there is a pair of casting portions connecting and restraining both sides of the bore).



It is very clear from the following photo that the area that has seized is in line with the connections across the bore of the lower casting areas.



The 2 principle causes of this failure are – (a) anything that makes the piston run hotter than it was designed to do – resulting in it expanding thermally too much (weak mixtures, too advanced ignition, higher coolant temperatures, loss of coolant etc) and (b) anything that reduces the piston clearance from the designed tolerance (that makes the bore smaller than it was designed to run at) – cylinder bore distortion, age related stress relieving.

When cold there is a designed clearance between the piston and cylinder wall that takes into account the normal heating up cycle of the engine. The piston always heats up and expands first because the source of heat is its crown (immediately above which combustion takes place). This means that there must be enough clearance so it does not expand so fast before the cylinder can catch up or it will “cold seize”.

Iron or steel liners do not expand as much over the same temperature range (or temperature gradient) as aluminium cylinders – therefore the cold clearance must be greater if they are used (usually by about one thousandth of an inch (0.0001” or 0.024mm for 80 to 100mm diameter pistons). Pistons expand by an amount in proportion to their diameter – so larger pistons need even greater cold clearances than smaller ones – and consequently the cold clearances needed for a large piston are even more than for a smaller one so that when hot the piston has the right running clearance. This is why manufacturers have largely abandoned iron blocks or liners if their designs include relatively large pistons and bores (although they can still be more acceptable with smaller bores and therefore often used more in multi-cylinder engines especially if they are cast in so that the expansion of the aluminium stretches the bores bigger without losing an interference fit (needed in dry liners)).

If the piston design does not have enough ovality, or the cold clearances are too small then if the engine is driven too hard before the cylinder block has fully warmed up – the piston can expand and take up the designed clearances too quickly and resulting a cold seizure. Similarly if for any reason the original bore size reduces (that therefore also reduces the designed clearances) it can result in cold or even hot seizures eventually.

Since the majority of the time that even a sports car is driven on public roads – the power output in use is really low (compared to the designed potential flat out) designers prefer to use aluminium cylinders so they can reduce the relative clearances whether hot, cold or in between compared to what they would have to set them at with iron liners (but for racing where the cold clearance is never an issue and they are only ever flat out iron or steel liners can work OK if the way they are fitted can hold them firmly at all temperatures).

After the problems caused by the Lokasil hypereutectic cylinder designs, for their next model range Porsche reverted to an Alusil hypereutectic cylinder block (as used very successfully and reliably in their previous 924S, 944 and 968 models).

However they were unable to use the same hard coated pistons that worked so well in combination with the Alusil blocks before.

The 924S, 944 and 968 engines also had an open deck cylinder so that created some flexibility.

Although the different "Ferrotec" piston coating they could use with the new Alusil engine is harder than a plastic coating we think it may not be quite as durable as the original Ferrostan coatings. We think this may be why the pistons were designed with less ovality (to spread the load over a wider area (spreading the forces over a larger oil film area to preserve higher oil film thicknesses).

The failures we have experienced (which are very small in number) were all seizures (both sides of the piston and cylinder bore and therefore unlike scoring).

The new cold piston clearances were also slightly smaller than the original Alusil blocks (or M96/7 engines) as well making any expansion of the piston or any shrinkage or distortion to ovality of the cylinder bore more likely to cause cold seizures.

On measuring the cylinders we found that some had shrunk in at the bottom in the thrust direction and closed in on the cylinder bores so that the resulting cold clearances were much too small.

The shrinkage was always at the same end of both banks (mainly cylinders 1 or 4 and sometimes 2 or 5) , the next cylinder (the centre one of three on each side) was less shrunk while the opposite end to the seized one was still perfectly round and not shrunk at all. We wonder if this is the result of the flow of molten aluminium into the casting moulds or the cooling rates of different sections at the ends of the blocks.

All the seizures we have experienced occurred in cold weather and with drivers admitting that they impatiently drove flat out very soon after setting off and therefore before the cylinder block would have totally warmed up, although whether it would eventually apply even in warm ambient conditions may depend on how much the stress releasing needs to move before it reaches a stable shape and size.

Looking at the design of the cylinder block – it is completely different to the M96/7 engines having removed the crankshaft cassette and therefore needing to include part of the casting near the bottom of the cylinders that could be machined to hold the crankshaft bearings.

This has resulted in 2 thick aluminium parts extending from one side of the cylinder bore to the other and to the outside of the cylinder block (which is significant) – connecting them in one solid casting (see photo).

This will be the last area of the engine internals to warm up because it is too far away from the coolant channels and piston (and it would take a long time for heat to conduct down to it) while oil warms up lagging behind coolant and it is only mainly oil splash from crankshaft rotation that would heat it up.

Furthermore the thicker a section of a casting is – the more castings stresses will be entrapped within it. This is because the cooling rate of the thicker casting areas will be slower so the outside face cools first but the inside remains hotter for longer.

The result of this is that the outside solidifies first while the inside is therefore still expanded bigger and then when the inside eventually shrinks it leaves a stress pulling the outside towards the inside.

In this case that stress will be pulling the lower bore area towards the centre in the thrust direction and tending to pull on the bore to make it shrink at the bottom and reduce the clearances.

The earlier 1997/8 t0 2008/9 open deck cylinders have nothing connecting the outer edges of the cylinders to the main block at the top or the bottom – so they are free to warm up and expand more quickly and with less stresses pulling at them whereas these closed deck cylinders, while having the benefits of more stability also have the potential downside of bore size and ovality distortion and shrinkage.

Furthermore - those piston clearances have already been reduced compared to the earlier (Gen 1) engines so the consequence is potentially worse.

Thanks to some information from customers it seems that Porsche introduced a coolant shut off valve around 2012 to help the upper cylinder to warm up (and run between 105 Deg C and 85 Deg C (depending on demand and loads) cycling between 110 and 80 deg C.
So it seems that this potential issue might have been recognised and they were trying to do something about it – although long term this continual stretching of upper and lower castings areas could (IMHO) tend to exacerbate the shrinkage.
It looks like they were trying to make the block expand quicker and then possibly changed their mind or moved it later (2015? – details still a bit hazy and subject to clarification).

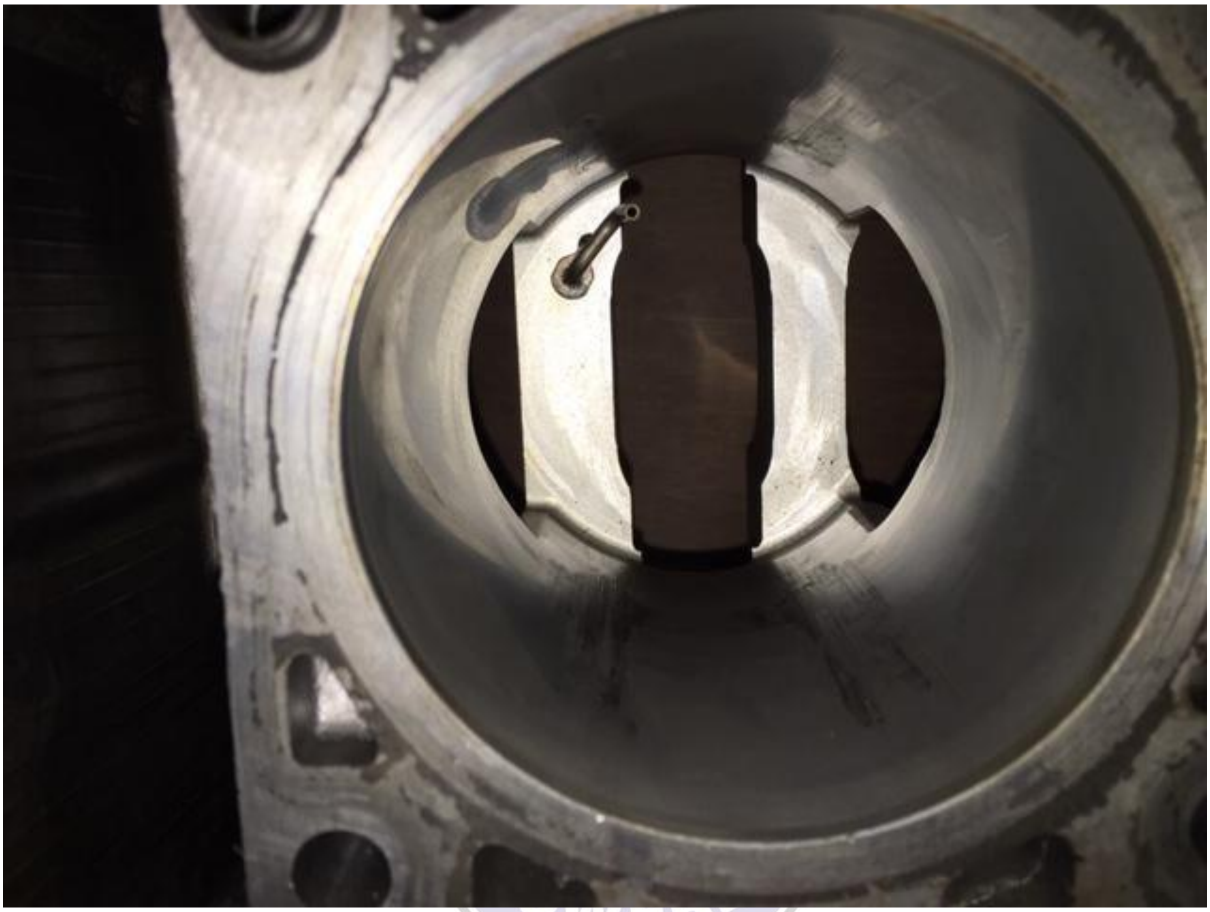
The problem is that this could make the lower shrinkage worse because if the upper cylinder area of the casting expands 1st and more than the lower area it is connected to – it adds a stress pulling the lower area outwards.

But when the whole casting has warmed up and shrinks - the whole of it shrinks together (and because the coolant is in the upper area that now shrinks later).

This means that even if the bores remained round – the bottom of the cylinder would be running with less clearances than the top as the block warmed up.

In cold ambient conditions the outside of the cylinder block will remain very cold for a very long time as cold air will flow across it as it is being driven and this difference in the expansion rate (and consequently the piston clearance at the bottom of the cylinder) will take longer to reach the right sizes.

But we cannot be sure if this gradual shrinkage is because of released cast-in stresses or the result of the difference in expansion and contraction rates during heat cool running cycles (or both) as described above. So we are not sure if the contraction was due to this uneven expansion rate between the different areas of the cylinder block over many heat/cool cycles - OR because of entrapped stresses during the casting cooling process – if this area gradually shrunk so that the bore went slightly oval and smaller in the thrust direction (where the piston is at its biggest), then it is even more likely that during fast warm up the clearances would be too small and the piston could seize.



Conclusion.

As a result of this analysis - we believe that all the **seizures** we have experienced have resulted from the bores expanding too slowly at the base or slowly and minutely shrinking in the thrust direction (as a result of age related stress relieving) to such a small clearance that the piston expanded bigger than the bottom of the cylinders bores (that in any case would be lagging behind the rest of the cylinder bores in thermally expanding) resulting in the seizure.

Owners who have got used to getting away with fast warm up cycles possibly for many years could suddenly get caught out by this process as the shrinkage gradually over many heat/cool cycles has reduced the clearances to a critical level.

Although better oils perform better – we do not believe that there is an oil that is capable of withstanding the pressures resulting from this combination of thermal expansion and bore shrinkage and therefore although we always promote the use of quality oils and frequent oil changes – we do not relate that to these seizures.
Thicker oils (or oils with expensive additives) can often result in greater sheer forces in the oil which in turn can heat it up to a higher temperature which in turn reduce the viscosity and therefore does not always result in a thicker oil film or slower dispersion rate under pressure.

We have not yet experienced **scoring** in one of these engines although we have seen photographic evidence of one example in a 3.6 model. In this one case the scoring is less deep and harsh as that we have seen resulting from a seizure and only on one side of the cylinder bore and nearer the centre and could have been the result of a higher cylinder or piston coating wear rate.

Because the information on this failure came from abroad we have no other information about any contributory factors so at this stage it may just be the result of some other typical engine problem like a failed water pump or coolant leak, blocked or failed injector etc. It could also be due to poor piston coating quality or a different concentration of silicon in the Alusil.

All the other reports we have had from round the World have demonstrated the same **seizure** failures as us and so at this stage we have nothing more to report and if we tried it would only be speculation after extremely limited evidence and probably be misleading.

Our Internet reports on this subject and model have initially been the subject of some disagreement with other specialists but after reading our opinion on the causes and seen the evidence we have provided to some of them (including cylinder bore measurements and video footage of the damage to the pistons and bores) have sometimes reluctantly come round to accepting our explanation as a valid one.

Among those that offer different conclusions are prominent contributors that have admitted that that have not even accurately measured damaged cylinders and pistons, or not been involved in their stripping and assembly (and not seen many examples), those that are happy to – in their words – “get more work through not advising owners how to avoid or reduce incidences of failures” and others whose explanations do not fit with logic or our experiences (of which claiming the problem is fuel when it initially only affects one bank) and/or fuel injectors (when we have successfully and for many years and thousands of miles never had to change them) cast obvious doubts on their relevance.

Statistical correlations do not require huge numbers to form conclusions. All that is needed is to identify the outcome correctly and list it and then apply engineering and scientific considerations to the problems and see how many of the physical and visual evidence they satisfy. With the admitted exception of bore scoring in M96/7 Gen 1 engines - all our explanations our conclusions came quickly and have stood the test of many years, huge mileages, racing success and hundreds and thousands of repairs.

Bore scoring in the M96/7 engines took longer to accurately diagnose (largely because it was initially described by the manufacturers as “the same as Alusil” which we now contest) but with perseverance and lots of expensive time consuming tests and analysis (at a level no other competitor to our knowledge has remotely matched) we eventually made all the evidence and engineering standards fit all the conclusions and as a result our solutions work so reliably the Internet forums have accepted their superiority over any alternative and this is the best and most reliable feedback owners could ever receive.

Additional comments included at a later date.

WARMING UP ISSUES WITH THE 9A1 GEN 2 ENGINE.

This subject of warm up procedures relating to the potential for cold seizures (like many others on this type of forum) is the subject of a classic mistake that many clever, capable and well intentioned contributors frequently make by becoming too focused on what they assume is the salient issue and then launching into perfectly well thought out and reported facts, figures, historical experiences and advice relating to what they think are the contributory factors

– that are very convincing (and usually accurate and correct in their reporting) but actually are not related to the actual cause of the problem at all and therefore miss the point.

Cold seizures are the result of the piston becoming larger in diameter than the cylinder bore they run in – in specific places - so that the pressure from the piston face on the cylinder wall overcomes the ability of the oil to keep the moving parts separated and the resulting heat generated leads to micro-welding and classic seizures.

Although both the coolant and oil temperatures influence the temperature of the metal forming those interactive areas it is the temperature of the metallic parts (and the rate at which they heat up) that directly influences the size they expand to and not the temperature that the coolant or oil has reached over delta time.

From cold - the heat gradient is highest at the top of the cylinder (where combustion is hottest and the head and top of the cylinders experience the temperature rise first).

Lower down the cylinder, the heat from combustion has reduced (as the expansion of gas reduces temperatures proportionally) and the exhaust and exhaust pipes are the furthest away – so the metal down there heats up more slowly than at the top of the cylinder.

Furthermore the very top of the piston Where the rings fit) is machined very much smaller than the cylinder bore (and is never going to expand enough to force radial interference) while just under the ring area the piston is tapered and is smaller than the biggest diameter (and closest to the cylinder wall) about half to two thirds down the piston measured under the rings.

This means that the part of the piston that is largest and the part of the cylinder that will expand the slowest will interfere (if they are going to) lower down the cylinder where cold seizures always occur and where almost all the evidence we have (and have seen or had reported from others) of Gen 2 engines – is located.

Although it is possible to make calculations for the thermal expansion of a free standing component (using the start and finish temperatures and the thermal coefficient of expansion) many people seem to forget that these calculations do not work if the material is constrained such that the cooler areas resist the expansion of the hotter areas.

This fact is the key to both understanding cold seizures and relating them to differences in the real world between the Porsche 944/968, the 911 M96/7 Gen 1 engines and the 911 9A1 Gen 2 engines - in which those constraining influences are very different.

Just dealing with thermal expansion from cold – and first looking at the 944/968 – the top of the cylinder is open deck and a free standing cylindrical tube that warms up quickly and is not constrained while the bottom has all the warming coolant reaching close to the cylinder base (deep coolant channels) and 100% of the coolant passing round the cylinders before flowing up to the heads. This makes the warm up and therefore the cold to hot thermal expansion rate relatively fast.

The Gen 1 M96/7 has both the top and the bottom of the cylinder free standing open deck and therefore although a smaller % of the coolant flows round the top of the block this actually enables it to heat up faster. So although the coolant only reaches the top areas (relying on the oil splash to warm the bottom of the cylinder) the bottom of the cylinder tube also warms up quickly from the heat being conducted through the oil film from the piston and the oil splash and spray tubes also because it is both a thin tube and un-restrained.

The Gen 2 9A1 engine is completely different and is closed deck at the top and bottom. This means that the whole of the cylinder block is homogeneously connected to the cylinders top and bottom (and therefore to the outer areas of the block which remain colder for longer) and therefore the cylinder bore is constrained from the rate at which it can thermally expand by the temperature that the whole of the cylinder block has reached internally and externally - and not just the cylinder bore area, coolant or oil temperatures.

The top middle and bottom of the cylinder bore will therefore warm up more slowly and expand more slowly in the Gen 2 9A1 engine.

Measurements and comparisons of the rate of coolant and oil temperatures rises (provided on the Internet and perfectly correct) does not correlate to the expansion rate of the cylinders in different parts of the engine and out of these three different engine examples the Gen 2 9A1 will have by far the slowest lower cylinder expansion rate and lag well behind that of the oil temperature.

There are other external influencing factors as well. The 944/968 engine is located directly behind the radiator and the oil cooler is low down in the cylinder block and this results in more heat passing over or reaching the internal and outside of the cylinder block, allowing it to heat up faster.

The Gen 1 and 2 engines have the radiators nowhere near the engine and the oil cooler on top – so the extremities of the cylinder blocks heat up much more slowly.

Now we must consider ambient differences. In freezing sub-zero conditions the engine is frozen from cold and even when it is running and heating up with both coolant and oil temperatures at their operating conditions – the outside of the engine casing is still cold and freezing air is flowing over it – conducting heat away and slowing the rate that the whole block is heating up and with it the rate at which the internal cylinder is able to expand and this constrains the rate of lower cylinder expansion.

The outside of the Gen 2 cylinder block on both sides is homogeneously connected solidly to the lower cylinder bore by a large and solid piece of aluminium that forms the area that the main bearings are fitted and as such the temperature of the outside of that casting restricts (or constrains) the expansion rate of the lower cylinder in exactly the circumferential position that the piston ovality is at its biggest (in the thrust direction) and therefore does influence the rate at which the clearance between the piston and the cylinder changes as the engine warms up. In contrast not only is the lower cylinder tube free standing but the M96/7 crankcase/block has a huge hole in its centre where a completely separate casting cassette that holds the main bearings and crankshaft – fits into – and therefore although there is a joint face between them the effect of any constraint is far reduced.

So despite all the completely correct Internet posted analysis of coolant and oil temperature rises with time (gradients), graphs and comment and the combined advice based on historical experiences of different engines etc (which is almost certainly right) unless there is a broader understanding of a wider range of issues that result from looking at all contributory factors first in much more detail (and being more familiar with the engine construction and how it all works) and identifying the most important ones (and understanding exactly what is going on) it is easy to get deflected from the actual cause and provide convincing data that seems to support an argument that actually has little or nothing to do with the cause.

All the above means that the 9A1 Gen 2 engine lower cylinder bore will expand at a very much slower rate than a comparison with a 944/968 or M96/7 Gen 1 engine and therefore could be more susceptible to cold seizures – absolutely!

We may differ in agreeing what those temperatures are during the warm-up phase and therefore how much the thermal expansion is under constrained conditions but it is in our experience more than 0.001” (0.025mm). This is very close to the standard piston to bore clearance of the Gen 2 engine

Now – pistons do deflect and if the oil quality is good can run with increased pressure between the piston and the cylinder bore for short periods when the clearance is tight by slightly deflecting the piston skirt (where it is biggest) inwards but does result in higher oil film temperatures between the piston and the cylinder bore and therefore poorer lubricity. If the revs are high the piston face friction is higher and if the throttle is being used fully open through to higher revs the resulting temperature between the piston and cylinder is higher – therefore it is more important in the Gen 2 engine to allow longer for the whole cylinder block to heat up and expand without constraining the lower cylinder bore until the clearances will work effectively.

Furthermore, because the Gen 2 has reverted to the 944/968 Alusil hypereutectic bore system - the hard iron piston coatings that were available (and are considered essential by some experts) are no longer in use and in our experience the new metallic coating is good but not quite as durable and we feel this might explain why the Gen 2 piston has a profile that spreads the load over a larger area of the piston face. But although this would help the piston to bore wear to last longer – it also means that with tight piston clearances anyway – any delay in lower cylinder expansion would be more likely to result in a wider cold seizure.

Although my example above used the freezing ambient conditions to try and demonstrate the issues better even a start temperature of say 15 or 20 degrees centigrade has minimal influence on those overall expansion rates between cold and fully hot all over cylinder block temperatures – it just makes incidences a little more likely (and therefore statistically more reported) the colder the weather is.

So before all the arguments begin – if the above is right – then the evidence would be that we would see more cold seizures is the winter and resulting from fast driving off from cold – and this is so far 100% of the feedback we have received.

But there is another additional factor we have also measured and proven to afflict 100% of the engines we have seen – that the bottom of some cylinders have slightly closed in smaller through age related casting stress relief than the size they were from new and during their lifespan.

This means that although the above explanation is valid (that the Gen 2 would be more vulnerable to cold seizures even if the cylinders remained perfectly round and the original sizes) it may well be that IF the cylinders remained at the designed bore size – they would survive even an impatient warm up in cold conditions. But the cylinders we have measured had shrunk by around half a thousandth of an inch (0.0005" or 0.0127mm) and this definitely would result in the cold clearances being too tight if the engine was driven under high power too soon.

However – as long as the car is not driven under high loads from cold – the temperature of the piston crown and faces (and the resulting expansion) is considerably reduced – so although the cylinder bore may be slow to expand it probably would not result in too tight a clearance.

Similarly as long as the revs are not too high then the friction between the piston face and the cylinder bore will be less (and so will the resulting piston temperature and expansion).

However driving too slow will delay the whole warm up to running temperatures and reduce clearances.

This means that in our opinion the best thing to do is to drive off slowly from cold without using too much throttle or maximum revs but probably driving at a speed and acceleration rate that most saloon cars drive at on speed restricted public roads – keeping up with the flow but resisting the temptation to deliver the performance that we buy these cars for – until the whole engine is up to designed temperatures and the clearances are sufficient.

Sometimes the simplest explanations and the publics general experiences and advice - are right – and this happens to be the case here.

Alusil (like all hypereutectic cylinders) will eventually (after very high mileages) wear the bore surface smoother and reduce the effectiveness of the oil film and so it is possible that (just like the 944/978) after many years a cylinder may score or seize as a result but I would expect this failure to be insignificant statistically.

Some contradictory explanations and advice have appeared from other respected sources. It would have helped us determine the proportion of failures caused by cold seizures to see pictures of the inside of the cylinders affected – but unfortunately in some cases the contributors have refused to provide information to support or go against this explanation while neither they nor others have yet measured a seized Gen 2 block or piston and therefore could not possible have been led to this type of investigation and conclusion (and probably would have agreed with it if they had).

It must also be clear to less naïve readers that there could be a business benefit from not contributing information that might avoid or delay engine failures.

Whether alternative advice or explanations are innocently reached and provided or not - sometimes (in fact usually) the simplest explanations and the publics general experiences and advice - are right – and this happens to be the case here.

However we never allow commercial influences to override genuine advice and will continue trying to explain the causes in such a way that the general public can follow and believe in. It is not easy or quick and hence this regrettably long but I hope completely convincing study will help some owners to keep their engines running reliably throughout their ownership.

N.B. We do not intend to enter into any responses that result from this report nor to explain deeper any associated issues.

We do eventually intend to set up a video studio and try and convey similar technical information contained in our various reports on video.

We don't know how successful or competent we will be nor how long they will take before we can release them for public viewing.
We cannot afford to divert our hard earned resources into creating them with the use of a sub-contracted film studio and staff with video expertise (as we did with the 2 previous videos on our web site) rather than apply those resources to testing and solving problems.

When we do get round to video presentation we intend to start going over what the relevant engine parts are called and look like and then expand into how an engine works and on to these specific issues listed above (and more new ones).

FINALLY

If you have managed to read the whole content you will now get some idea of the amount of effort and time we have put into researching the problems and testing and manufacturing the best solutions. I hope you will also have picked up on the expertise we have and how we applied it.

You will find that some others pad out their promotions with a lot of time spent on things no one disputes and have no connection with the actual causes of the faults or the merits of different solutions. It is only when people are confident in their knowledge and research that they are prepared to expose every detail to public scrutiny as we have here and that is because we know what we are talking about.

When you are competent enough to correctly identify the causes of a problem it becomes very much easier to figure out the best solution, but finding the right cause is essential otherwise your solutions will be based on things of no consequence.

Specialists are naturally protective of their knowledge and public acceptance of their expertise and will often defend their conclusions even when they themselves are not sure or even know they are wrong and then rarely go into too much detail in case it exposed their mistakes.

Modern marketing can influence the public into buying into the best advertising and promotion and the added profits they generate benefit the shareholders and can sustain the costs and the resulting increase profits even when the actual product is inferior. Spending more on research and development, testing, equipment, machinery, training and product quality will probably provide better solutions as a result but will leave less in the kitty to compete by marketing and advertising their resulting superior product. So if the customer is not an automotive engineering expert they are vulnerable to making poor decisions.

I hope that this document has cleared up a lot about the problems of these engines and the different solutions offered and has enabled you to make better decisions in the future. If not, then at least I tried my best to help and my conscience is clear if you have a subsequent 2nd failure.

If you are still unsure about the merits and disadvantages of some different solutions perhaps this final question and answer list may help.

(1) If roller or ceramic IMS bearings were a good option – why did Porsche solve that problem with a larger ball bearing – as we have?
(2) If dry iron liners were a good solution, why have we received so many that failed, why did Porsche not fit them to their GT3 and Turbo engines and why had so much effort and investment been put in by the industry to avoid them (except generally where they are cast in or used with smaller pistons)?
(3) If the cooling of the M96/7 engines was not marginal why did Porsche extend the cylinder coolant depth in the Gen 2 engines (and the answer explains why we ribbed the outside of our alloy wet liners – the only solution that does so?
(4) If the Lokasil engines ran reliably without scoring when fitted with the original hard iron coated pistons but scored when fitted with plastic coated ones – how can that change not be a significant factor?
(5) If cylinders can run on for thousands of miles after scoring, how can it be the cylinder surface finish that is the problem and not the release of silicon particles?
(6) Why would a sharp irregular silicon particle (in some cases as big as the bore clearance) not be able to damage the piston and cylinder bore when the thrust load over the now minute area would obviously penetrate the oil film and piston plastic coating?
(7) Has anyone else published explanations and photos that reveal why the plastic piston coating is an obvious weak spot?
(8) Who else can combine racing success with totally "IN HOUSE" remanufacturing machinery and equipment to be able to apply their own quality control throughout?
(9) Who else has such a universally acknowledged reputation in the market?

We at Hartech have no intention of expanding our business because it is well balanced between a lot of different disciplines, equipment and factory space and the only practical way to expand would be to double in size – which we fear would reduce the excellent level of customer service we provide together with a more remote management. Furthermore – as we are accepted as the best provider – those that go elsewhere and then have to fork out for a second rebuild have learned their lesson and come to us next – so we get most of the work anyway and have no reason to expose the issues that some alternatives result in.

Having added oversized engines to our already busy standard engine remanufacturing set-up – demand already exceeds our capacity so we have no incentive whatsoever to have provided you with all this valuable information except to help you take on board our position, compare the differences and make up your own minds about who has carried out the most professional and extensive research and testing, who has the best reputation and who to trust over disputed issues.

Please let us know (by E-mail to admin2@hartech.org) if you found any of this content helpful or you learned from it as we have several other very interesting reports of similar levels of research into different aspects of these engines and general tuning that you might be interested in.

(5) Polishing marks in Hartech Nikasil bores.

(1) For some time – now that owners and specialists are aware that bore scoring can occur – owners have been requesting camera shots of their own cylinder bores to check their condition.

This has resulted in some paranoia when they see polishing marks in our Nikasil cylinder bores and assume mistakenly that they are bore scoring.

The nearest I can get to an analogy is a windscreen with marks where despite the hardness of glass and the softness of rubber - the wiper blades have put minutely small dulling to the otherwise shiny surface that can be seen sometimes like a smear over the surface. However this is not the same because they are usually caused by bits of grit being stuck between the blade and the windscreen whereas the polishing marks are caused by minute irregularities in the roundness of the bore and piston rings needing to be run in on first start-up.

If you measure an original Lokasil bore after say 80K you may find it is around 6 or 8 thou oval and if you measure it at 10 degree intervals round the bore there will be lots of peaks and troughs but because the bore is more dull it is not obvious to the naked eye or a boroscope.

Similarly iron liners will have little ovality but be worn in patches slightly but not show.

Nikasil in contrast is harder and will retain a superb roundness for years. On the odd occasion when a racing version has blown a big end or dropped a valve - we have almost always been able to recover the engine with the original Nikasil cylinders - the surface is that good. It is possible to reduce the hardness of the Nikasil plating and this also reduces any polishing marks – but the result does not last as long without increased wear rates so we prefer a harder coating

However it is difficult to match ring material to it. The 911 SC 3 litre and 3.2 Carrera models had Nikasil bores and less "polish marks" but the rings were worn down to a point at the ends after around 70K while the compression dropped at low revs making the engines. run at low power until the camshafts kicked in with better timing where they designed the power band.

The following picture shows broken cylinder studs and the difference between a new and worn Carrera piston ring after 70K.

The bores will show little or no polish marks because the rings are softer but then worn out at 70K whereas the rings in the M96/7 engines last much longer but are harder and will last for at least double that mileage but will polish mark cylinders with absolutely no detriment to the running of the car.

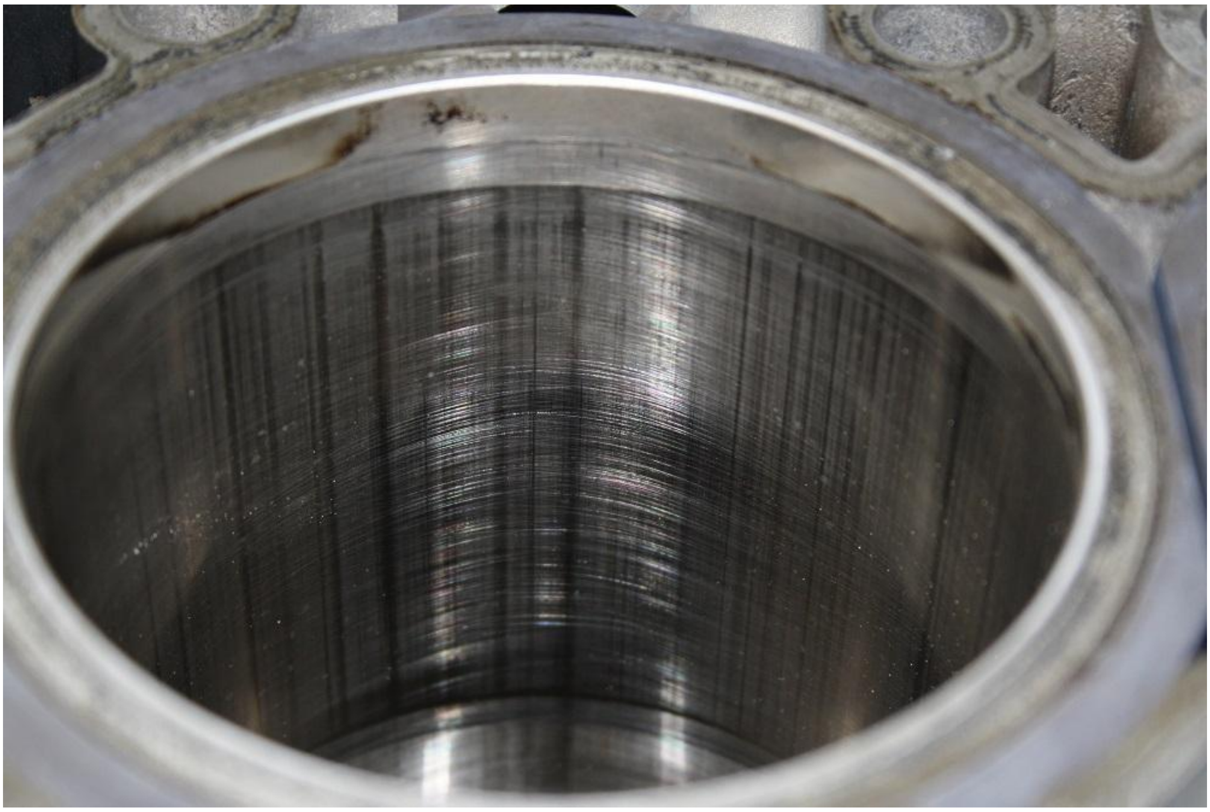
It is really unfortunate that the public - aware of the problems - and rightly wanting boroscope reports on their cars (or before buying) and mechanics and engineers do not understand the differences between polish marks and scoring (not really their fault though).

Typical shiny bores being measured by us for surface finish.

The machine that measures the surface finish that we use when we final hone our cylinders.

Nikasil is applied a few thousandths of an inch thick and if it ever scored there would be deep obvious grooves in the surface. Lokasil scored would be even deeper grooves and usually over a wider width.

The following picture shows typical polishing marks of a high mileage Hartech cylinder that might appear but have no depth and cannot be measured by normal bore measuring equipment.



Hopefully you will see that this is nothing like the scoring shown in the following picture.

Porsche cylinders can and do crack, and/or go oval, and/or score. Despite miniscule comparative resources we (and some others) provide a better alternative.

We could fit rings that did not polish bores but they would wear out after 50 to 70 K, resulting in oil consumption and reduced bottom end torque - what is the problem with some polish marks and an otherwise long lasting permanent solution that is better than anything else on the market?
It's all down to microscopic measurements of surfaces.

Under huge magnification a cylinder bore in the vertical axis plane looks like a saw tooth and so does the surface of the ring that touches the bore.

Even though our honed bores are around 10 times more round than some new Porsche bore (which we have in stock on a number of new blocks), the surface still under magnification is still uneven circumferentially.

When the engine is first run the minute high spots on the ring touch the minute high spots of the bore where the point of contact is like the tip of a saw blade tooth and all the forces on the ring (from combustion) push the load onto a very small area and because load over area is high it polishes the surface in vertical lines.

After a minute or two running the sharp points on both the ring and bore are microscopically flattened and the load is now spread over a much wider area and the load/unit area is not sufficient to polish the bore any more.

The result is a much better fitting rings to bore contact surface than you will get from any other combination providing good compression and long life but leaving those small polished marks in the cylinder that have no measurable depth but are sometimes visible.

This process is what all engines and all parts in engines undergo during the "running in period" and it is what it is all about.

We do concede that very early bore scoring has little depth and looks similar but the difference is that it can be measured and deteriorates where Nikasil does not. So we do admit that when the Lokasil original surface starts to release silicon particles that the piston rubs up and down the bore to initially lightly score it - the result can look similar to polishing - but those of us familiar with the differences can detect it using our own camera (but perhaps not others) and it is obvious when it gets worse.

Later on they wear all over but Nikasil is hard enough once a few high spots are rubbed down to last almost for ever especially being oleophilic.
These are chatter marks where the rings has in the first ever running touched a few high spots and bounced on its way up and down.

Interpretation of markings is important and every mark must have some depth - but in that case all the cylinders are scored all the way round in an angles plane where you see the honing marks - which are (if you want to be awkward) scores.

The interpretation however of "bore scoring" is different - being deep grooves cut into the surface and not insignificantly microscopically polished areas that were originally minutely high spots where the ring touched those small high spots a little harder when first run and because the load then per unit area is high - managed to polish them down a little to create an even more round bore and better ring to bore fit, higher compression and less blow by - but due to the highly polished nature of Nikasil on reflection - marks the bore where the running in took place.

It has been argued that are polishing marks must still be scores even though they have no measurable depth but we dispute this too because the polishing marks you see come about because on a miniscule level measuring microns, the very round surface of the bore has come into contact with the hard piston ring on first running and if you think about it this is only happening if the point where the marks are is where the curved surface of the bore and the ring are touching just a little bit more than on either side leading to a typical pressure point (which is what running in is all about).

This means that if a score is a cut "IN" a surface this is not that scenario as it is the opposite and can only occur if the 2 points in contact are actually microscopically proud.

What is happening is that the surface is being rubbed until it conforms more to the shape of the ring and the resulting bore is even more round than it was before.

This is why it is in no way bore scoring even on a micro level but rather an improvement on the fit of 2 new parts - like all running in is meant to achieve.

The marks we get in Nikasil are not caused by large loose silicon particles as the particles not only almost never become loose but are much too small and are always much smaller than the oil film. The only reason for marks is therefore the microscopic touching of two hard surfaces until a minute amount is rubbed back after which the additional surface area is spread over a wider area and insufficient in force to rub against the surface.

These marks therefore are running in marks that make the surface even a better fit than when manufactured.

Unlike Alusil or Lokasil (where silicon is embedded in a bigger aluminium matrix) Nikasil forms a solid alloy of very much smaller Silicon particles in Nickle and the result is like a tubular shim well bonded to the aluminium substrate - as a result it does not release harmful or large silicon particles and even after debris might get into a cylinder (dropped valve etc) we can usually recover it without damage.

It does retain oil as well but also the angle of the honing, type of diamond hones used, stroke rate and surface finish are finely controlled by us and reproduce the very best all round result for a bore finish.

It is a choice we make to either have perfectly smooth bores when photographed (but rings wearing our prematurely) or polishing marks of no depth or consequence that last almost for ever.

(6) RE-GRINDING Porsche Crankshafts.

Whether manufactured as specials from billet or original Porsche crankshafts – they are both expensive and so if a bearing journal is damaged or worn - it has been a reconditioning standard repair option to re-grind the journals a little smaller and fit +0.5mm or +1.0mm replacement oversized shells.
This has always worked well largely because the crankshafts used to be case hardened (by increasing the carbon content of the steel at the surface in a variety

of different ways) creating a hard journal surface depth that would still be deep enough to be hard after the re-grind.

However those crankshafts had to be heated red hot and then quench hardened and this distorted them slightly so the manufacturing process had to first make the crankshaft, then grind the journal diameters to just above the final size, then harden them and finally put them back on the grinding machine and finish the slightly out of round distorted journals to their final size – which worked really well.

There is another type of surface hardening called nitriding (which instead of carbon infuses nitrogen into the surface of the steel) which can be carried out at a lower temperature and does not require quenching from a temperature that might cause distortion – so these can be less expensive to manufacture.

Although there are many different ways to nitride a component – all have a small number of differences to case hardening.

(1) It creates a brittle white layer on the surface often up to 0.0005" (or 0.013mm) that is brittle and uneven and may need polishing.
(2) Although lengthy heat treatment can provide a deep case it is usually less deep than in traditional case hardening unless expensive materials are used.
(3) Manufacturers can save time and money not only by using nitriding to save the final grinding process but by reducing the time being infused with nitrogen and the white layer depth by only hardening to a relatively thin hardness depth.

We had standard crankshafts tested and discovered that they had been nitride hardened to a depth too thin for the bearing surface to still be hard after a regrind of 0.25mm, and even less hard after a regrind of 1.0mm.

Many years ago we did obtain oversized shells and re-nitride (with calculated allowances for the white layer and polishing) and the results proved satisfactory but we didn't need to put them into production because most failures had either bent the crankshaft too far out of true to use, or they were worn through to the softer layer under the thin hard skin too deep to regrind anyway and sufficient used crankshafts became available.

Then among the engines we receive that had failed (and had been originally rebuilt elsewhere), we received some where a journal diameter had been reground (sometimes only one journal) but it had (as we would have predicted) worn through the softer smaller journal prematurely.

This means that – once again – some specialists had been unaware (or disinterested) in the longer-term effects of re-grinding a shallow nitrided surface, making the short-term cost saving in doing so become hugely more expensive the second time around.

Like so many other aspects of different rebuilding specifications, those trying to save a small amount of the costs of doing it right end up paying out even more the second time around.

Although billet nitride hardened crankshafts made from top quality nitriding steels can be hardened to a depth that allows for re-grinds most mass produced modern crankshafts are not because most modern production engines are unlikely to ever be reconditioned – but simply be replaced instead – so the issue never arises.

If a regrind is carried out with or without re-nitriding and polishing the journals there is then the question of who is responsible if the bearing fails again, the heat treatment business, the crank grinder or the engine builder. In fact this is the problem with a lot of the cheaper repair options some offer since the cost of stripping out the engine and a full rebuild is much higher than the cost of any usually sub contracted repair – which usually limits their responsibility to the cost of the part of the job they did (that is if they accept responsibility anyway). This is also the advantage of using a specialist that carries out all their work themselves "IN HOUSE" like us, as it makes our position clear from the outset.

Thinking about "repair products" in general, it is also important to understand that running an engine until failure may lead many to assume "it's OK, because I can just get XYZ repaired easily" – without realising that the problem with that approach with crank bearings is that it isn't only the crank which is affected. The carrier and connecting rods are usually damaged and then the debris usually wrecks the oil pumps, pistons & potentially cylinders etc and in a worst case the rod will break resulting in the internals being smashed beyond repair.

We still think a preventative re-build is the best route to go down when the mileage is creeping into "classic crank bearing failure territory".

Some owners may then like to consider using the opportunity to increase the capacity so they feel like they're getting a little more out of it.

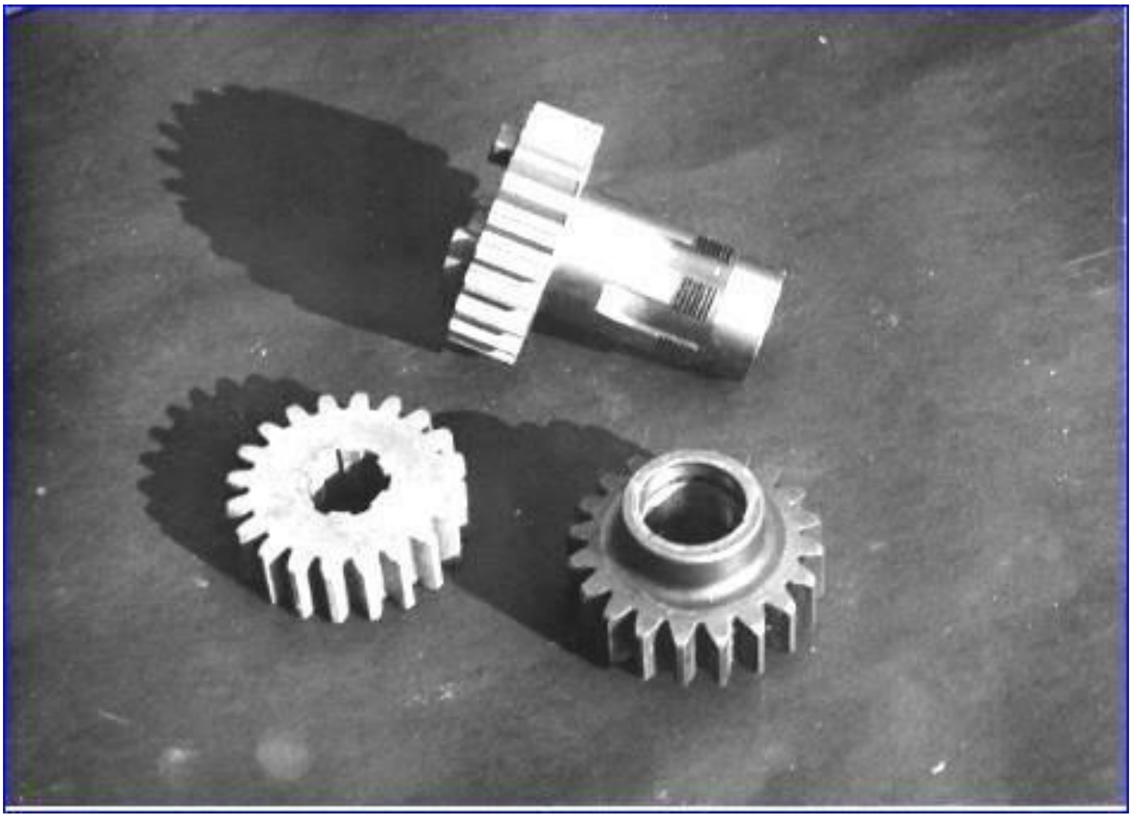
Barry Hart (Technical Director Hartech Automotive).

Barry Charles Hart Born 1946 United Kingdom.

Raced motorcycles 1965 – 1969 while studying at Kingston University (Norton and Yamaha) with fellow student Tony Ryan (Norton).

They say necessity is the mother of invention and while combining a 6 year engineering apprenticeship with a graduate education – they wanted (but could not afford) close ratio gearboxes for their Norton Dominators so decided to try to make one on their own - only to discover a revolutionary new way to design one incorporating fewer parts than the opposition and therefore costing less despite being of even higher quality. Just the following pictured components (two new manufactured gears and one std earlier 3rd gear) achieved higher 1st 2nd and third gears and brought them closer to top.

This led to Worldwide demand and so after graduating they started Barton Motors designing and manufacturing close ratio gearbox's and engine parts and re-designing commercial components for local businesses. A couple of years later they split the business with Tony staying in Woking with the commercial side of the business and Barry moving to North Wales to concentrate on racing motorcycle components.



In the next few years he found other ways to achieve the same outcome making fewer new gears to achieve the same or better ratios and designed, manufactured and sold C/R gearboxes for many Japanese and Italian Motorcycles, including a 6 speed gearbox for World Champion Barry Sheene that replaced the previous 5 speed version for his Works Suzuki TR500 bike (later adopted by them) shown in the next photo.

He also built a 3 cylinder 350 cc water cooled racer that broke the lap record at Brands Hatch and the 500cc Sparton racer that was the fastest at the Isle of Man TT in it's first race and the successful sales of which went on to achieve wins all over Europe including 1st and 2nd at Europe's fastest road race - the North West 200).

160mph Tait tops our trap

THOUGH not the fastest bike of the week, Barry Hart's Suzuki-based Sparton three was the star of "Motor Cycle's" Highlander speed trap, operated by former sprinter Arthur Breese. Ridden in its first race by Martin Sharpe, the Sparton was equal-fastest Senior machine — clocking 146 mph, the same as the works Kawasakis of Mick Grant and Barry Ditchburn.

Odd man out among the horde of following Yamahas was Bo Granath's air-cooled Husqvarna twin, at 144 mph.

Surprisingly, Grant's lap-record-breaking 750 cc Kawasaki three was beaten by two mph on the Friday afternoon by Percy Tait's ex-Lansivuori works Yamaha four. But even Tait's 160 mph was four mph short of Jack Findlay's speed on a works F750 Suzuki two years ago.

At 152 mph, Barry Ditchburn's 750 cc Kawaski was six mph slower than Grant's, while Alex George's four-carb Harley-Davidson twin was the fastest five-hundred in the Open Classic race, with 149 mph. Best British seven-fifty was Dave Croxford's Norton, 142 mph.

The fact that the best 350 cc Yamaha in the Open Classic event (Noel Clegg, 147 mph) was three mph faster than that in the Junior (Gerry Mateer, 144) probably reflects slightly better weather conditions.

Roger Nicholls' Shepherd Suzuki did well to get 10th place among the Yams, with 141 mph.

Yamahas naturally dominated the 250 cc speeds, from Granath's 139 mph downward. The fastest non-Yamaha was Ralph Watts' 182 cc Honda, at 110 mph.

A swirling wind cut production-machine speeds by comparison with last year's. Naturally, the big bikes were affected less than the small ones. Slippery Sam was only one mph down on 1974 and the best BMW (Martin Sharpe/Abe Alexander), two mph. The best five-hundred (the Tom Loughridge/Ian Richards Suzuki) was three mph down, while the quickest 250 cc Suzuki (Richard Hunter/Mick Scutt) and 250 cc Yamahas (Godfrey Benson/John White and Richard Stevens/Peter Casey) were five and six mph down respectively.

With 138 mph in the 1,000 cc Sidecar event, Dick Greasley's 700 cc Yamaha added one mph to last year's best — clocked by Rolf Steinhausen's 680 cc Konig. This year, Steinhausen dropped a shade to 135 mph. The fastest BMW (Siggi Schauzu's 560 cc outfit) clocked 134 mph to last year's 133, but Bill Currie's 850 cc Weslake was up from 120 to 128 mph.

Speeds in the 500 cc Sidecar race were generally down on last year's. For example, Heinz Luthringhauser's BMW dropped from 133 to 126 mph, while this year's best (Steinhausen, 128 mph) was six mph short of Mick Boddice's 1974 best with a similar engine.

Mac Hobson's Yam four outfit was a not exception. Equal fas this year, it had found mph since last year. of the British Mag flat fours was Gra Milton's 122 mph clocked 125 with larger engine). By parison, Tony Wakefi outfit was timed at mph and Robin Will son's at 111 mph.

THE TOP TEN

	mp
P. Tait (700 Yamaha)	16
M. Grant (750 Kawasaki)	15
B. Ditchburn (Kawasaki)	15
P. Grove (700 Yamaha)	15
A. George (500 Harley-Davidson)	14
W. A. Smith (700 Yamaha)	14
C. Williams (385 Dugdale Maxton Yamaha)	147
N. Clegg (350 Yamaha)	147
M. Sharpe (500 Sparton)	146
M. Grant (500 Kawasaki)	146
B. Ditchburn (500 Kawasaki)	146

RACE-BY-RACE SPEEDS AT THE HIGHLANDER TRAP

500 cc SENIOR

	mph
M. Sharpe (Sparton)	146
M. Grant (Kawasaki)	146
B. Ditchburn (Kawasaki)	146
C. Williams (Dugdale Maxton Yamaha)	145
J. Williams (Yamaha)	145
B. Granath (Husqvarna)	144
E. Roberts (Dugdale Maxton Yamaha)	144
H. Kassner (Yamaha)	143
A. Rutter (Yamaha)	143
H. O. Butenuth (Yamaha)	143
P. Gurner (Yamaha)	143
C. Mortimer (Danfay Yamaha)	142
G. Mateer (Yamaha)	142
S. Tonkin (McVeigh Yamaha)	141
R. Heath (Yamaha)	140
P. Cott (Yamaha)	140
W. Simpson (Premier Yamaha)	140
R. Sutcliffe (Crooks Suzuki)	139
B. Murray (Albion Yamaha)	139
W. A. Smith (Yamaha)	138
M. Moffatt (Yamaha)	138
J. Scott (Yamaha)	138

350 cc JUNIOR

	mph
G. Mateer (Yamaha)	144
T. Herron (Yamaha)	143
N. Clegg (Yamaha)	143
R. Sutcliffe (Yamaha)	143
C. Mortimer (Danfay Yamaha)	142
J. Williams (Yamaha)	142
A. George (Vesco Yamaha)	142
B. Granath (Yamaha)	142
H. Kassner (Yamaha)	141
R. Nichells (Shepherd Suzuki)	141
J. Scott (Yamaha)	141
P. Cott (Yamaha)	139
A. Rutter (Yamaha)	139
P. Gurner (Yamaha)	139
B. Guthrie (Danfay Yamaha)	138
C. Williams (Dugdale Maxton Yamaha)	138
W. Henderson (Yamaha)	138
D. Chatterton (Chat Yamaha)	138
S. Tonkin (McVeigh Yamaha)	138
B. Randle (Yamaha)	138

250 cc LIGHTWEIGHT

	mph
B. Granath (Yamaha)	139
N. Clegg (Yamaha)	138
I. Richards (Yamaha)	138
A. Rutter (Yamaha)	137
H. Kassner (Yamaha)	137
T. Herron (Yamaha)	137
G. Mateer (Yamaha)	137
C. Mortimer (Danfay Yamaha)	137
P. Casey (Yamaha)	137
D. Chatterton (Chat Yamaha)	136
M. Sharpe (Yamaha)	136
J. Kidson (Yamaha)	136
A. George (Yamaha)	135
J. Williams (Yamaha)	135
C. Horton (Hayne Line Yamaha)	135
G. Barry (Yamaha)	135
J. Holmes (Rea Yamaha)	135
C. Williams (Dugdale Maxton Yamaha)	134
G. Marsovszky (Yamaha)	134
S. Tonkin (McVeigh Yamaha)	134

1,000 cc OPEN CLASSIC

	mph
P. Tait (Yamaha)	160
M. Grant (Kawasaki)	158
B. Ditchburn (Kawasaki)	152
P. Grove (Yamaha)	152
A. George (Harley-Davidson)	149
W. A. Smith (Yamaha)	149
C. Williams (Dugdale Maxton Yamaha)	147
N. Clegg (Yamaha)	147
T. Herron (Yamaha)	145
G. Pantall (Suzuki)	145
C. Sanby (Suzuki)	145
A. North (Yamaha)	145
R. Sutcliffe (Yamaha)	145
H. Kassner (Yamaha)	145
C. Mortimer (Danfay Maxton Yamaha)	142
D. Croxford (Norton)	142
A. Rutter (Yamaha)	142
D. Pendlebury (Kawasaki)	142
J. Kostwinder (Yamaha)	142
P. Cott (Yamaha)	142
E. Roberts (Dugdale Maxton Yamaha)	142
N. Tuxworth (Yamaha)	142

500 cc SIDECAR

	mph
R. Steinhausen (Busch Konig)	128
M. Hobson (Yamaha)	128
H. Luthringshauser (BMW)	126
G. O'Dell (Konig)	125
G. Boret (Konig)	125
S. Schauzu (BMW)	124
S. Sinnott (Yamaha)	122
D. Greasley (Yamaha)	122
G. Milton (British Magnum)	122
G. Pape (Konig)	120
T. Janssen (Konig)	118
R. Wegner (BMW)	116
H. Schilling (BMW)	116
A. Wakefield (British Magnum)	115
D. Plummer (Konig 113)	113
M. Boddice (Konig)	112
R. Williamson (British Magnum)	111
E. Schons (BMW)	110
R. Dutton (Yamaha)	110
M. Potter (BMW)	110

1,000 cc SIDECAR

	mph
D. Greasley (Yamaha)	138
R. Steinhausen (Busch Konig)	135
S. Schauzu (BMW)	134
G. Boret (Konig)	133
G. O'Dell (Konig)	131
T. Ireson (Konig)	129
P. Williams (Imp)	129
K. Graham (Suzuki)	129
D. Lawrence (Limpet)	129
W. Currie (Weslake)	128
D. Plummer (Konig)	126
G. Milton (British Magnum)	125
T. Janssen (Konig)	125
R. Hanks (Imp)	124
O. Haller (BMW)	122
F. Cornbill (Honda)	121
B. Bardsley (Suzuki)	121
A. Rivett (BMW)	121
H. Schilling (BMW)	120
R. Dutton (Yamaha)	120
B. Moran (MB Norton)	120
J. Davies (Imp)	120

250 cc PRODUCTION

R. Hunter/M. Scutt (Suzuki)
G. Benson/J. White (Yamaha)
R. Stevens/P. Casey (Yamaha)
S. Jones/W. Simpson (Yamaha)
C. Mortimer/W. Guthrie (Yamaha
A. North/M. Patrick (Yamaha)
R. Cope/R. Forrest (Yamaha)
S. Ward/G. Waring (Yamaha)
G. Hardwick/L. Notman (Benell
W. Robertson/S. Murray (Suzuk
C. McGaham/B. Toleman (Benel
W. Barker/P. Rates (Yamaha)

500 cc PRODUCTION

T. Loughridge/I. Richards (Su
C. Williams/E. Roberts (Hond
R. Sutcliffe/W. Rae (Honda)
W. A. Smith/P. Tait (Honda)
R. Bowler/M. Rollason (Suzuk
P. Gurner/D. Saville (BSA)
R. Bisbey/N. Watts (Honda)
M. Kirwan/D. Logan (Suzu
D. Danks/T. McKane (Honda
F. Rutter/E. Cornes (Honda
C. Revett/S. Parrish (Honda
A. Rutter/B. Murray (400 Ho
G. Fogarty/W. Ingham (Su
M. Pexon/R. Hirst (Suzuki)

1,000 cc PRODUCTION

D. Croxford/A. George (Tr
M. Sharpe/A. Alexander (
R. Heath/G. Barry (Honda
G. Pantall/T. Newell (Ka
D. Lunn/D. Cash (Ducati)
S. Griffiths/D. Williams (Tr
H. Butenuth/H. Gluck (Bh
P. Darvill/S. Eldridge (Ho
C. Porter/M. Wigan (Hon
R. Knight/A. Walsh (BMW
H. Dahne/W. Dieringer (
D. Grant/A. Capstick (Tr

NORRIE WHYTE REPORTS THE NORTH-WEST 200

MART TOPS TON TO WIN IN ULSTER

Percy Tait and his big Suzuki skim along the coast road from Portrush to Portstewart.

250cc leaders Tony Rutter and Ian Richards take a wary line under the railway bridge where the combination of oil and water make things very difficult.

THE Welsh Sparton concern scored its first international victory in Saturday's rain-lashed North-West 200 road races in Northern Ireland.

Martin Sharpe, from Brackley, Northants, averaged just over 100 mph to beat fellow-Sparton Frank Kennedy by three seconds after 42 minutes of squelching action on the 10.08-mile Portstewart - Coleraine - Portrush public roads circuit.

As they dodged the worst of the puddles and forgot about the cold, Sharpe and Kennedy swapped positions four or five times as they battled for the lead they were handed when Stan Woods' Suzuki twin nipped up at half distance when he had a 22 second lead.

The 250 start, with favourites Ray McCullough (Yamaha, 8) and Tony Rutter (Yamaha, 1) lining up alongside Eddie Roberts (Yamaha, 25).

First, it was Ballymoney rider Kennedy — bidding for his first pure road race win — who had the advantage, then Sharpe got the bit between his teeth.

Kennedy wasn't so lucky, though. His Sparton went on to two cylinders intermittently as he battled with Sharpe.

Behind the two Spartons came Percy Tait on a works Suzuki-4.

Starting with a pusher from the back of the packed grid, Tait had overjetted the powerful Suzuki to ensure that it would finish, but he couldn't get full

...tional.

In slippery water, he beat Tony Rutter by 1.6s after 80 miles of torture.

After Woods' 750 Suzuki-3 stopped for fuel when leading, Tait and Rutter had it all their own way.

The freezing and soaking fans — about 50,000 of them — were thrilled as only a few yards separated the pair for the entire race.

Race favourite Mick Grant finished third, a minute behind Rutter.

Irish eyes had begun the day with a wet smile for Ulster hero Ray McCullough led the 350 seven-lapper from start to finish. His only challenge came in the early stages from up-and-coming Irishman Joey Dunlop until his Yamaha expired approaching Coleraine.

By the end of the first lap, McCullough had his Yamaha in a 26-second lead from Phil Carpenter, who in turn was hotly pursued by Sam McClements, Rutter, Lee Heeson, Geoff Barry and Charlie Williams...

Martin Sharpe sticks a knee out as he rounds the new magic roundabout on his way to winning the 500 on a Sparton.

— sidelined him after only one lap.

Another Irishman, young Steve Cull, led for a couple of laps until his Yamaha also packed up.

That left Rutter and Ian Richards dicing it out for the lead.

On Mrs. Dorothy Whitehouse's Yamaha, Richards led into the last lap and held the advantage all the way to win by a fraction of a second from Rutter.

For Richards, a 29-year-old Liverpudlian now working as a motor cycle mechanic in Birmingham, it was his first international win. His previous best win was a national at Silloth several years ago.

Dunlop finished third, clear of a stream of Irish riders headed by Gerry Mateer.

PROVISIONAL RESULTS

Pictures: Derek McIntyre and Clifford McLean

Further work for Suzuki resulted in making their 750 works triple racer into an 850 and the works RG500 into a 650 (later to become the basis of the following years works Suzuki 750 class bikes).

He then designed and made the World's most powerful 750 4 cylinder, 6 speed, disc valve two stroke (named the Phoenix 4) that won numerous Internationals and several Isle of Man TT's.

motor cycle

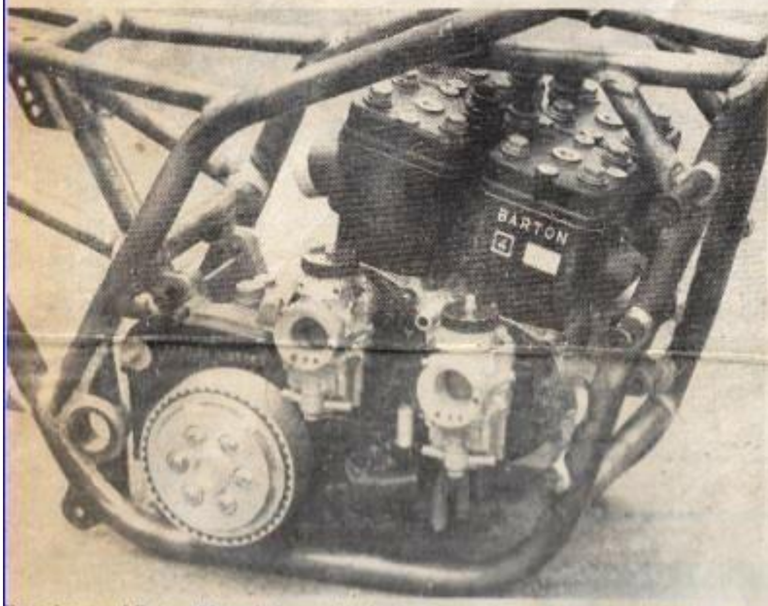
WEEK ENDING 8 JANUARY 1977

CA

...and

see page 18

SPARTON'S WORLD BID

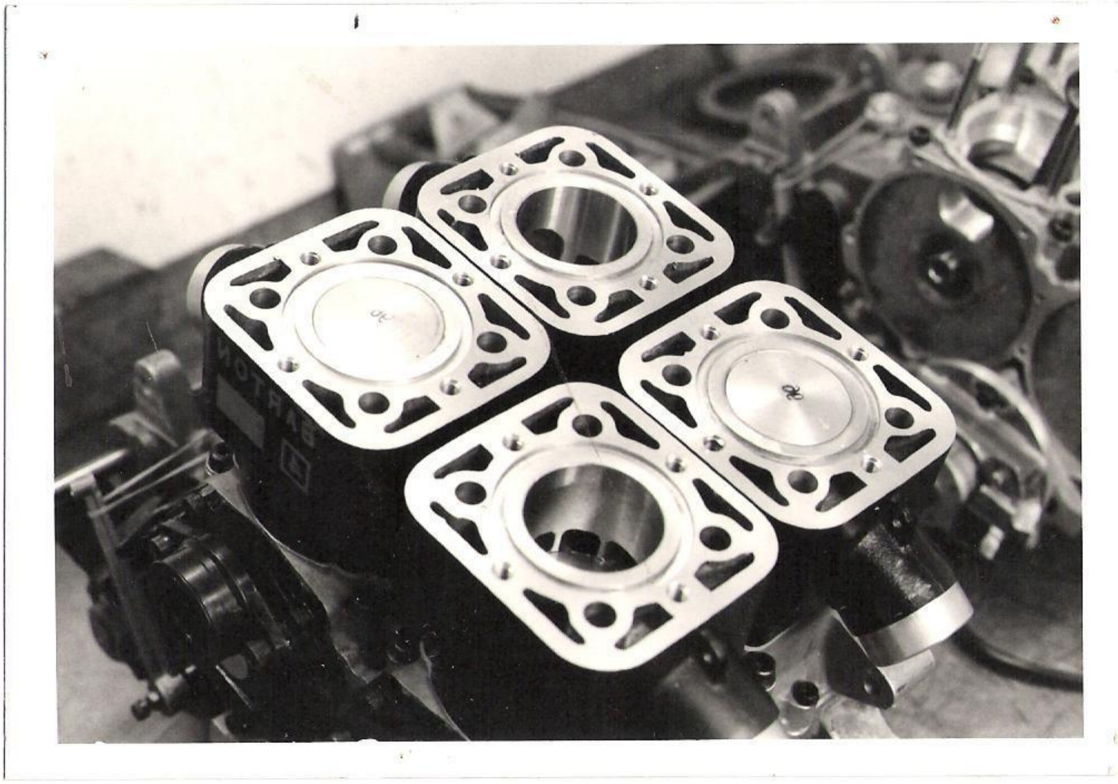


First picture of Barton Motor's four-cylinder 750 cc racing engine after being housed in its Spondon Engineering frame. Suzuki-style, the disc-valve engine has a square four layout. More pictures, page four.

BARRY HART's ambitious plan to put Great Britain back on the racing map with his four-cylinder, two-stroke 500 cc and 750 cc Spartons took a giant stride forward at the weekend when wealthy Midlands businessman and racing enthusiast Sid Griffiths agreed to back the project.

Sid, sponsor of South African Kork Ballington, Derby's Geoff Barry and New Zealander Stewart Avant, has agreed to finance and run the Sparton works development machines.

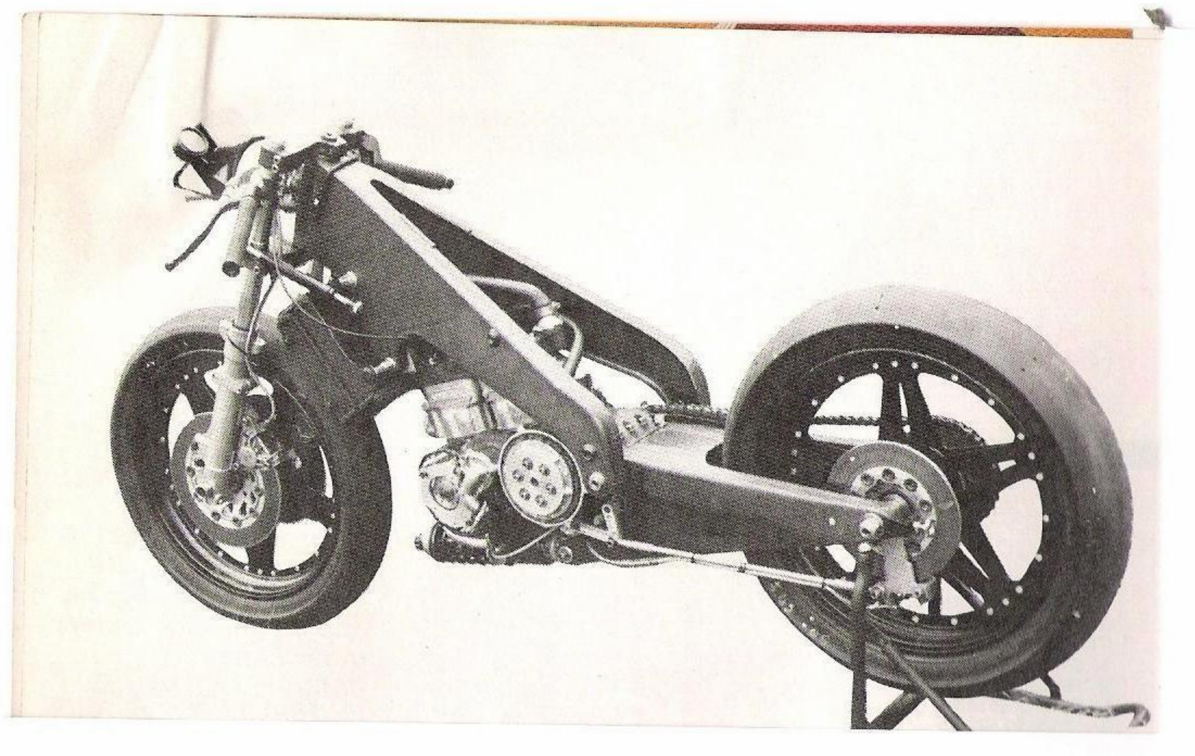
Initial testing of the prototypes will be done by Geoff Barry at the soon to be re-opened Donington circuit. This is ideally situated near Barry's home and close to Spondon Engineering where the frames and cycle parts for the Spartons are being made.



He later won the contract to design and make the futuristic **Silver Dream Racer** for the Film with David Essex, Beau Bridges and Christina Raines (still available). Photo below showing a very youthful Barry with the stars and the bike in 1979.

By now dreaming of playing a major role in the rebuilding of the British Motorcycle Industry – but realising it would take more than his self-employed experience and resources to provide the other pieces of the jigsaw necessary, he decided he should accepted Armstrong's plc's offer to buy his profitable business and move to Bolton as their director in charge of Engine development. While there he designed and made 250 and 350cc engines (seen in the photo below) for the Armstrong race team and a new 3 cylinder 500.

He also helped with the development of the World's first carbon fibre framed racers (shown below using the engine as a stress member for the suspension) that won the British Championship in consecutive seasons (winning every race with lap records), 3rd in the French GP and numerous International wins. Picture of both chassis and the Armstrong 350cc engine.



Disillusioned with the lack of progress of Armstrong management (and eventually realising his aim to help rebuild the British Motorcycle Industry was probably impossible), combined with needing more free time with his young family, he moved on to a Carbon Fibre manufacturer in charge of the new product development section (which including solving a problem for Ayrton Senna's Lotus race car) and winning innovation awards for contributions for Composite Design Manuals for "Metal Engineers" from Eureka Magazine.

He later joined a large aerospace company as General Manager (where he revolutionised the first stage manufacture of the Rolls Royce RB 211 titanium fan blades transforming the profitability of the business), and moved on to several other UK managerial roles finally running the composite subsidiary of Aerospace Engineering plc.

Throughout this time he indulged his childhood love of Porsche's owning just about all models from his early '20's (a 356C, 924, 944's, 911's and 968's) and was Founder and the first Chairman of the now thriving UK's "Porsche Enthusiasts Club".

Finding he was still not enjoying the politics and short term management styles of British main boards he decided he had learned enough about the short comings of British Industry to get out of the rat race and return to self employment in 1987 and indulge his lifelong love of Porsche cars by opening Hartech Automotive.

After quickly becoming recognised as the UK's 924 and 944 specialists and moving on to 911's, he introduced a revolutionary and unique monthly paid Maintenance Plan that spread the cost of ownership and shared the risk of failures (and still thrives today).

Not expecting to ever need to use his original engine design and manufacturing skills again – it all fell into his lap when it became obvious that a new engine designs by Porsche for their Boxster, 996 and 997 engines had some fundamental flaws and that there was probably no one else in an independent Porsche specialist business with a more suitable background to solve them and set up small batch production.

That expertise (and his confidence in the outcome) encouraged him to invest in and set-up an engine re-manufacturing section with two machine shops (with brand new CNC machines), stripping, cleaning and assembly rooms and streamline the re-manufacture of these engines (made after 1998) enabling Hartech to become the World's leaders turning round up to 1/day for an International market (see 2 videos on Hartech's website www.hartech.org).

In 2012 he decided it would be good for the workforce (and fun for him 30 years on) to go back to racing by entering the UK Porsche Club Championship with a Boxster and despite no previous car racing experience (and building the entire car from scratch IN HOUSE) they followed the path already established in the motorcycle racing World by unexpectedly winning the first race. Over the next 2 years the team grew to 4 cars (including a 996) and won the most races, classes and the team awards.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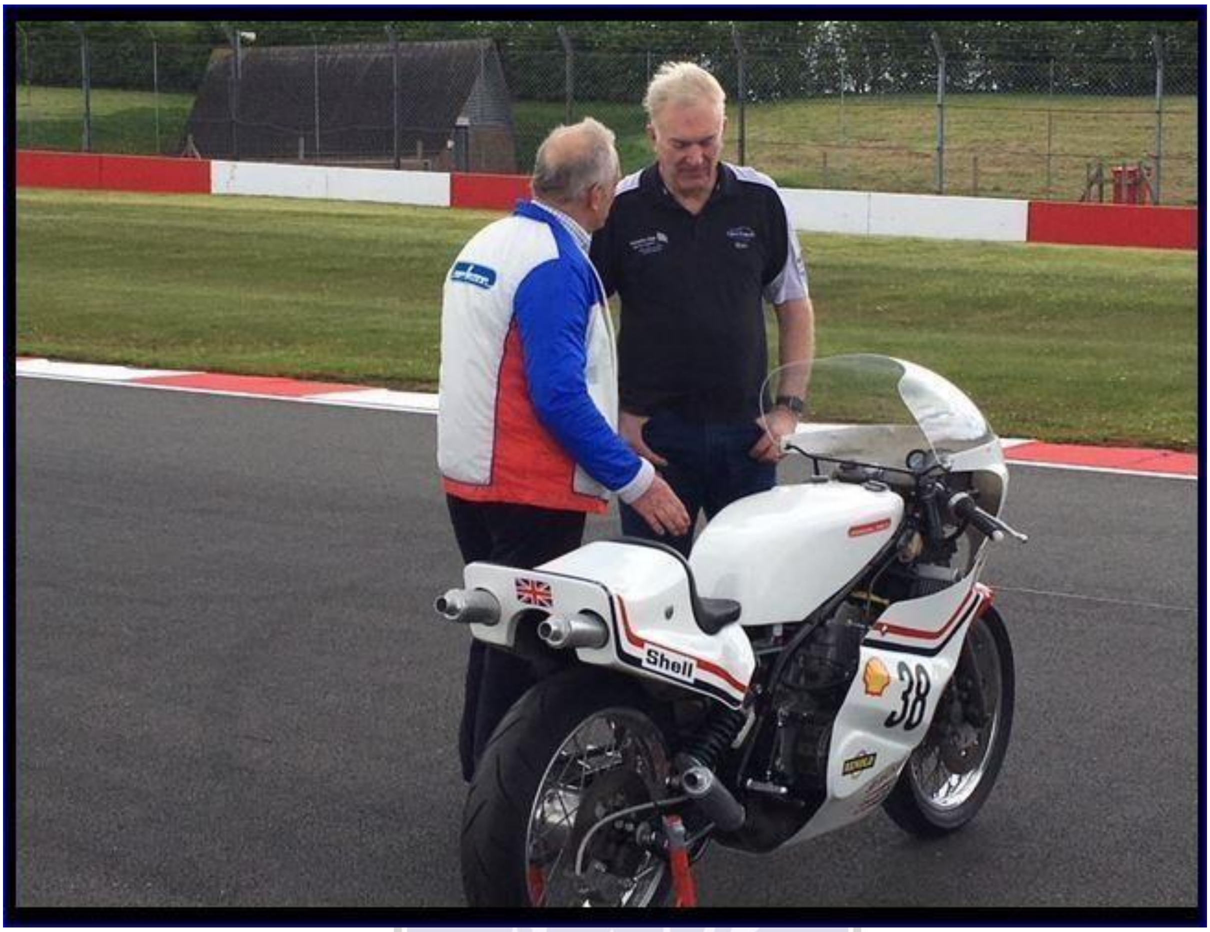
BAYLIS & HARDING
Hartech
PORSCHESHOP
PIRELLI

In 2015 pressure of work keeping up with ever increasing demand for remanufacturing Porsche engines resulted in Hartech pulling out their racing team and instead building racing engines for selected competitors in the UK Porsche Club Championship (class 1 and 2) and the BRSCC Boxster Championship – winning each class and each Championship year on year with 100% reliability.

By improving the technical specifications and with the engines proving reliable enough to withstand higher output – he spearheaded the development of larger capacity versions for 6 models.

Having made the internal development of his staff his main priority since the beginning he now has more time to head up the Hartech technical team while writing his fully documented book about his motorcycle racing exploits (seen below on the RHS (hair now receding) at a 40 year reunion of race winning bike, rider and designer for "Classic Bike Magazine editorial July 2018"). a



He is also trying to help Porsche owners by conveying the benefit of his knowledge and experience when confronted with poor, misleading and often costly misinformation presently filling Internet forums by writing technical corrections and reports for Porsche owners to help those interested make the best choices (a lot of which can be seen on www.hartech.org including some videos).

When asked how he managed his unique and lifelong engineering success, he put it down to finding out to his surprise - that lots of apparent experts didn't know as much as they thought - because they too easily accepted what technical books contained, what others said or what was accepted as right - without thinking it through for themselves – missing out on vital knowledge as a result - as if over-education missed out the thinking part of the learning process.

With a natural suspicion and distrust of other sources he felt more comfortable ignoring established explanations and instead worked things out from first principles often finding errors in basic understanding that others had made and as a result finding better solutions.

This combination of experience, an excellent engineering education and hands on machining and manufacturing enabled him to make things that racing success proved superior (despite his relatively minor resources). He also reinforces the point that however good or well-funded marketing and promotion is - the best test of competent engineers is when there is nowhere to hide – in racing against all comers.

He feels it was a very lucky coincidence that when he decided to have an easier life enjoying his love of Porsche's for the final part of his working life - his previous experience designing and making racing engine parts combined with working in industry at senior management level ideally suited solving their unexpected problems.

However - he feels his greatest achievement has been to build and train a brilliant workforce that it will continue to drive Hartech to more success and to excel long after his eventual retirement.

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Barry Hart, Technical Director, Hartech Automotive