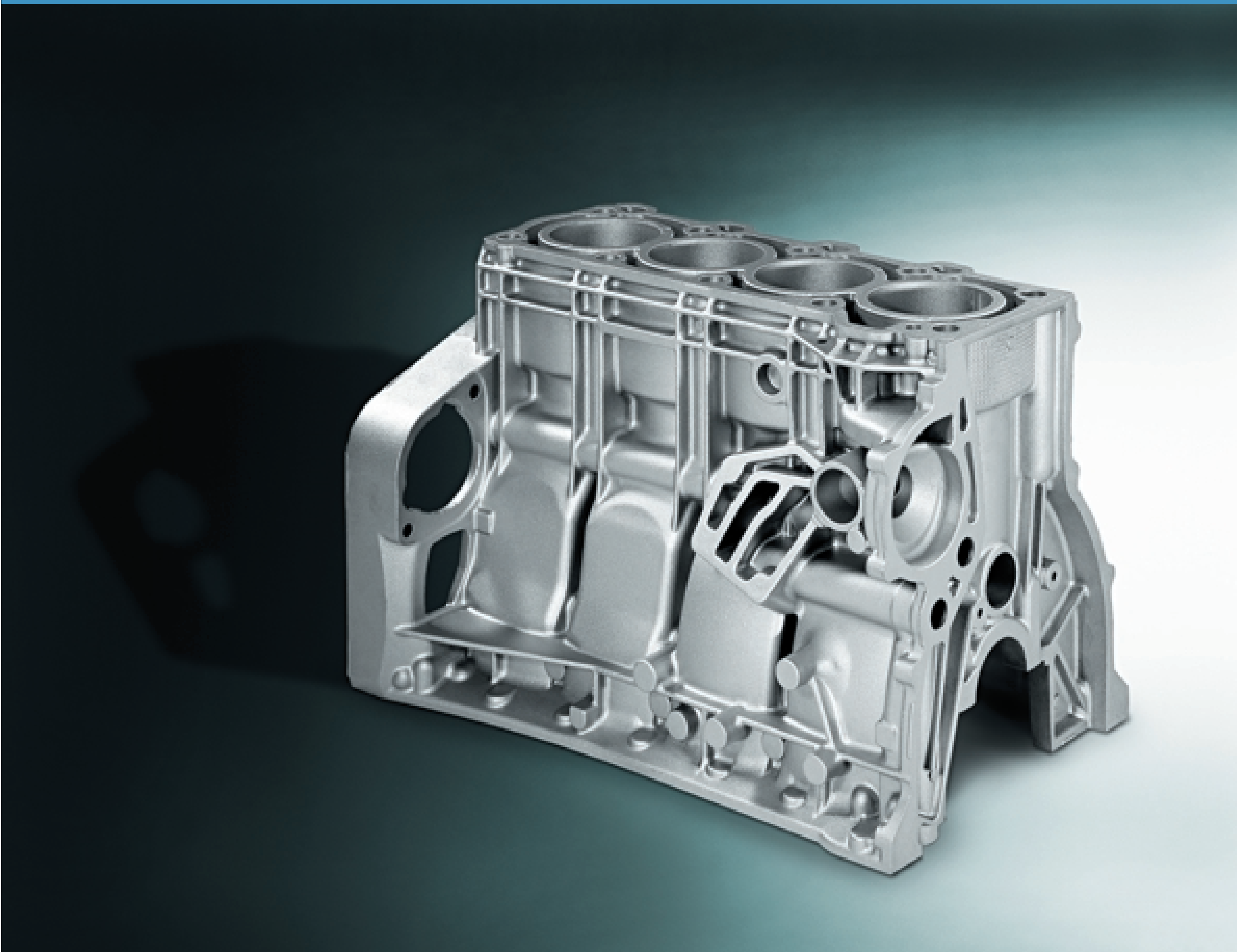
Highly efficient solution specifically for passenger car in-line engines

HIGH-PRESSURE DIE CAST AND SQUEEZE CAST ENGINE BLOCKS MADE OF ALUMINIUM



ALUMINIUM TECHNOLOGIE

Aluminium engine blocks enhance light weight-construction

Castings of aluminium are making an ever more significant contribution to leveraging light construction potentials in modern passenger cars. The heaviest individual component, the engine block, has meanwhile taken on a key role.
If we consider the enormous number of in-line engines produced – four-cylinder and recently also three-cylinder ones – the cost-benefit aspect must have absolute priority.The replacement of grey cast iron with aluminium for engine blocks therefore presupposes low-cost concepts.

Concept diversity for aluminium engine blocks

Contrary to the engine blocks produced so far, mostly made from grey cast iron based on a uniform concept which already incorporates the cylinder bore surfaces when a perlitic structure configuration is chosen, there are many diverse options in the case of aluminium. These relate to the concept modules of type of engine block design, alloy, casting method and cylinder bore surface, in which case manifold incompatibilities have to be taken into account. The overriding aspect is therefore the compatibility of the concept modules. A further constraint for the concepts which are viable in principle results for concrete engine development projects from the targets and general specifications with respect to engine function, elemental engine characteristics (number and arrangement of cylinders), annual outputs, costs of castings (and whole base engine systems), optimisation potential, environmental aspects and recyclability. This situation has led to a large number of marketable concepts.

Aluminium engine blocks and high-pressure die casting method

■ Economic aspect

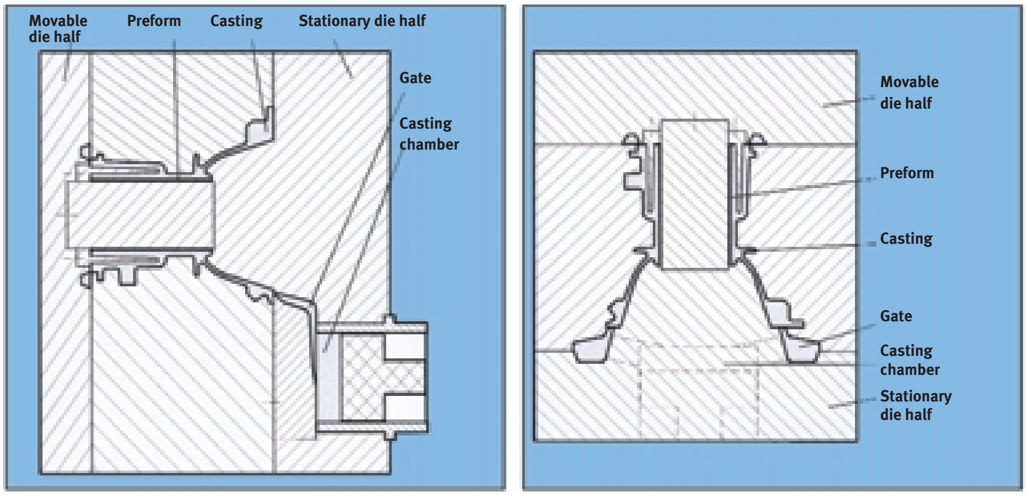
From the economic aspect, for mass produced engines, highly automated casting methods using sand moulds (“core package process”) whose sequence time is not bound to the solidification are principally competing with high-pressure die castings. In the especially harshly contested, cost-sensitive market segment of four-cylinder engines, the latter casting method is unrivalled in the present situation with respect to cost-effectiveness.

■ Design features

High-pressure die casting methods compulsorily prescribe mouldability in steel. Hence the open deck design is mandatory. It is obvious, however, that with aluminium engine blocks this design finds better general acceptance today. A distinctly reduced water jacket depth and co-moulded cylinder bores have created a variant besides the conventional open deck which exhibits a sufficiently rigid cylinder area even without a closed deck, meeting the requirements of most in-line engines. For niche applications in closed deck design, a suitable technology is available in principle for developments in the form of DOEHLERCORE, a core withstanding high pressures and high thermal stress.

■ Properties

High-pressure die castings provide extremely accurate contours and distinguish themselves by, in comparison, extremely narrow dimensional, shape and position tolerances. It should be mentioned that there are certain disadvantages inherent in the shot-like die filling. This leads to gas inclusions (microporosity) in the components. Moreover, a certain tendency towards local shrinkage-cavity formation can hardly be eliminated. Because the gate always solidifies in the course of this process, there is no re-feeding possibility. On the other hand, pressure die castings reach appreciable strength in thin-wall areas. The high-pressure impact makes for extremely fast heat dissipation. The structure near the surface is therefore remarkably dense. Low-pore vacuum-assisted high-pressure die casting is an elaborate process with complex pressure casting dies for engine blocks, for engine blocks, but it is more and more widely applied.



Different gate systems of conventional high-pressure die casting (left) and vertical squeeze casting (right)

■ Delimitation high-pressure die casting/squeeze casting

In the classic squeeze casting process, in contrast to the conventional pressure die casting, the engine block is gated in a different casting position (high-pressure die casting: block "lies" in horizontal position; squeeze casting: block "upright"). The gate is arranged at the bottom of the side wall(s). However, there is a current tendency also to gate the high-pressure die castings on both sides, for which purpose the engine block has to be turned by 90° compared with conventional dies (the engine block's longitudinal axis moves to vertical).

Whereas the plunger is guided horizontally in conventional high-pressure die casting machines, filling the die at a high speed, in the case of squeeze casting this is done rather slowly and in "classic" machines with a vertical movement. The die is therefore filled without significant gas inclusions. In contrast to conventional high-pressure die castings (that are conditionally weldable, but do not allow artificial ageing because of a concomitant destruction at temperatures just below 500 °C), such components can be fully heat-treated and welded. Most high-pressure die cast engine blocks are not annealed (volume-stabilised) at temperatures around/somewhat above 200 °C for cost reasons, although this is feasible in principle. Due to the target conflict given by growth-conditioned cylinder distortion in long-term operation without stabilization (annealing) on the one hand and cylinder distortion through potential loss of internal stress at operating temperature caused just by stabilisation (annealing, at the same time stress relieving), this situation has to be checked very carefully for each specific case.

In the case of squeeze casting, die venting and avoidance of oxide inclusions may constitute certain problems. Satisfactory die filling can be ensured by process optimisation in squeeze casting. Moreover, for squeeze casting the general wall thickness should be somewhat more generous than with high-pressure die casting, in order to safely avoid cold-running problems. It is only with the high-pressure die casting method, which means very fast filling of the mould, that extremely thin-walled, shell-like structures can be cast. This is why typically high-pressure die cast engine blocks are comparatively somewhat lighter. The rigidity deficits due to the material aluminium are compensated by conspicuous ribs, cambering and preferably closed-profile elements (e.g. suitable tunnel-like configuration of the oil drain ducts).

Due to its special aptitude, the squeeze casting method is mainly used for infiltration purposes, which means, for example, for the production of local aluminium matrix composites. In this respect, modern high-pressure die casting machines with real-time control, i.e. the possibility to influence plunger speed and pressure build-up, can today be considered equivalent to vertically operating squeeze casting machines.

■ Cylinder bore surface

The lowest cost option consists in solving the cylinder bore problem of high-pressure die cast engine blocks by means of cast-in grey cast iron liners. The respective armouring of the cylinder bores is indispensable because the hypoeutectic alloying variants suitable for high-pressure die casting do not provide the necessary tribological properties. However, the use of cylinder bore liners presupposes a heterogeneous character of the engine block. In the case of grey cast iron liners with differing properties, this is becoming more than obvious. When casting in liners, the smallest gap (between liner and casting) is achieved in combination with high-pressure die casting, and this is expressed by comparatively good equivalent

Conventional cast iron liner for high-pressure die casting application

Cross-section of a cylinder with cast-in iron liner (high-pressure die casting engine block)

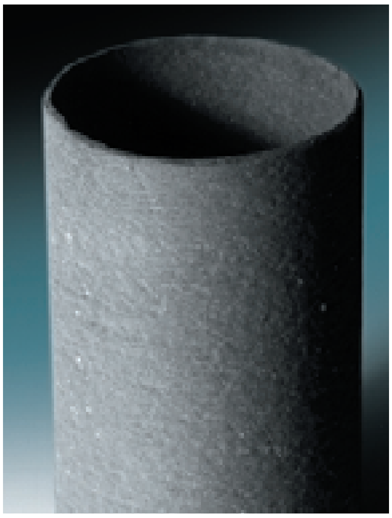
thermal conductivity figures. Liners made of suitable aluminium materials can, according to the present state of the art, only be cast in by high-pressure die casting because they have to rely on extremely short solidification times due to the melting-through risk. However, the outer-face area fusion of aluminium liners with the aluminium casting is not satisfactory. A mechanical clamping in conjunction with BMI-cast iron liners (BMI = bimetal interlock) is possible.

Cast-in liners have residual stresses which are difficult to control. The situation is rendered even more difficult by the casting tolerances and deformation. Development efforts which should not be underestimated are therefore needed to control multifactor-conditioned cylinder distortion problems with statistically anticipated potential functional disadvantages, especially in long-term operation.

■ LOKASIL® Technology

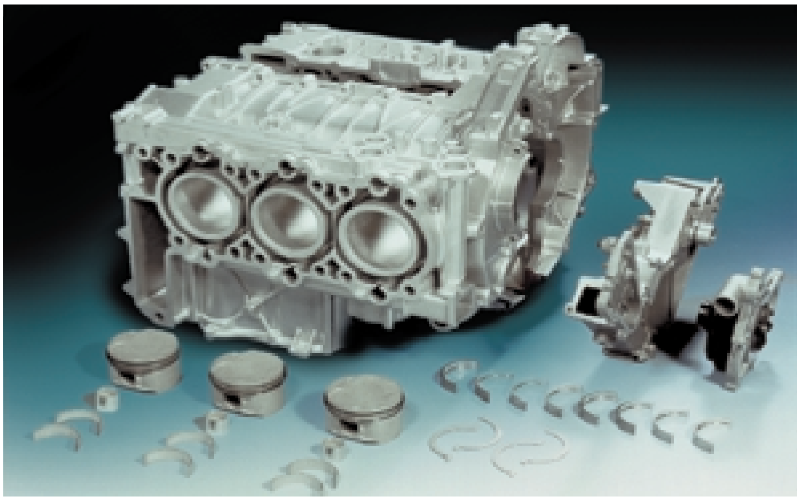
Monolithic and/or quasi-monolithic conditions largely avoid the described disadvantages. In the early 1990's KS ATAG started the development of the local composite material solution LOKASIL® as the better alternative to the liner. The gapless insertion of the composite material in its surroundings is generated by the infiltration of highly porous hollow cylindrical bodies (preforms) made of silicon with a base alloy for casting under high pressure as an artificial counterpart to the metallurgically produced ALUSIL® (registered trademark of KS ATAG, hypereutectic alloy AlSi17Cu4Mg). The infiltration presupposes the squeeze casting or real-time controlled high-pressure die casting process with solid steel dies.

With these casting processes, it is not possible to cast ALUSIL® with satisfactory process reliability. That is why KS ATAG has developed an equivalent concept with local silicon enrichment for high-pressure die casting processes: LOKASIL®. The holistic approach is apparent in a new honing process, worked out in line with the development of LOKASIL® and tested for mass production, which includes the mechanical "uncovering" of the silicon grains. This process can replace the chemical etching process and produces an excellent, tribologically optimised surface. Only monolithic and quasi-monolithic concepts with their fundamental advantages (see for example the product information sheet "Low-pressure Die Cast Engine Blocks made of Aluminium") additionally support unproblematically the frequents request for cylinder units of maximum compactness (minimum land width between cylinders = minimum cylinder distance). With Porsche as pilot customer, the series introduction of LOKASIL® engine blocks was successfully launched with the Boxster and the new water-cooled "911" now called Carrera (identical engine blocks in two bore/swept-volume variants). The LOKASIL® II variant of the LOKASIL® material family is applied in this case. If, due to minimum dimensions between the cylinders and/or elevated component temperatures, demands on strength are higher, the aluminium oxide fibre-reinforced LOKASIL® I variant is available. Further LOKASIL® variants with specific application targets are in the development stage.

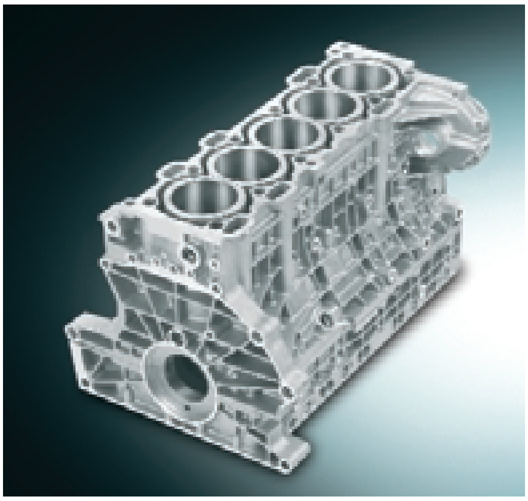


Silicon preform

LOKASIL® cylinder bore surface (local silicon enrichment)



PORSCHE Boxster LOKASIL® engine block with Kolbenschmidt Pierburg system components



VOLVO in-line 5-cylinder diesel engine block cast in high pressure die casting with cast-in BMI cast iron liners

Examples of implementation

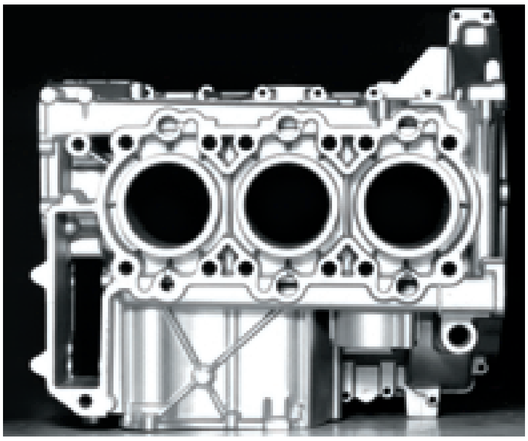
Today, KS ATAG is producing engine blocks according to the most diverse – own and outside – concepts in combination with high-pressure die casting methods and a standard alloy* in series. In conventional high-pressure die casting, these are:

- DaimlerChrysler four-cylinder engine blocks for A class
  - SI engines with cast-in "Silitec" liners (aluminium liners based on powder metallurgy; DaimlerChrysler technology)
  - Diesel engines with cast-in BMI-cast iron liners
- Volvo five- and six-cylinder engine blocks in in-line design, cast-in grey cast iron liners
- Volvo bedplate for five-cylinder engine blocks.

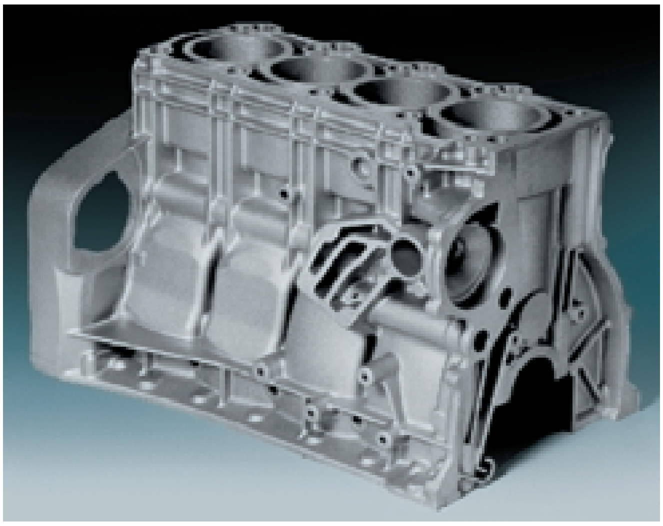
In classic squeeze casting are cast in series:

- Porsche opposed-cylinder engine block halves with LOKASIL® cylinder bore surfaces.

*Alloy 226 (VDS) = AlSi9Cu3 – high-pressure die cast secondary alloy.



PORSCHE Boxster and 911 Carrera opposed-cylinder engine block half with LOKASIL® cylinder bore surfaces (squeeze casting)



DaimlerChrysler in-line four-cylinder deep skirt engine block, cast in high pressure with cast-in liners (gasoline engine: aluminium liner ("Silitec"); diesel engine: BMI-cast iron liner)

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