Innovative piston technology for passenger cars and utility vehicles by KS Kolbenschmidt

Profound piston system expertise
**Introduction**

The major trends in state-of-the-art combustion engines, such as downsizing, supercharging and direct injection, intended to comply with required exhaust gas limits and to reduce fuel consumption and CO₂ emissions, remain drivers of innovation for new piston technologies. For modern piston systems, this means they must simultaneously comply with the demands for reduced friction, low weight and increased durability at maximum strain.

**New nano-reinforced diesel alloys improve passenger car pistons**

In 2012, KS Kolbenschmidt GmbH presented an alloy for diesel pistons in heavy-duty utility vehicle engines. The pistons have been enhanced by nano-phase, intermetallic separations and have made an impression with the formation of a particularly fine structure that results in considerably increased strength. In the meantime, we were able to transfer the experience gained from the new material and develop a diesel piston alloy for passenger cars. The alloy is a symbol of the company’s ongoing successful development of high-temperature aluminium materials for diesel pistons. We have already launched initial series development projects.

The objectives at the core of the new alloy that has been adapted to the specific framework conditions in diesel engine applications were increased thermal fatigue (ThF) and high cycle fatigue (HCF). For this purpose, we optimised not only the alloy composition but also the tool concept and the procedures.

The microstructure of the new alloy (Figure 1) is characterised by a higher quantity of intermetallic nano phases compared with KS 1295, the previous standard alloy. This is based on the addition of special alloy elements with a lower solubility within the aluminium matrix.

![Figure 1: passenger car diesel piston with remelted piston bowl edge made from the new KS309 NDA high-performance alloy](image1)

**Figure 2:** high cycle fatigue as a function of the thermal fatigue for the KS 1295 standard alloy and for the new diesel alloy

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<th>Material Composition (Microstructure)</th>
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<td>Grain refinement due to HSDC</td>
<td>+35% ThF</td>
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<td>ThF cycles @ Tₘ₉ = 350 °C</td>
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Figure 2 illustrates the high cycle fatigue of the new alloy and KS 1295 (HCF@ T = 300°C) as a function of the thermal fatigue (ThF@T_{max} = 350°C). The combination of alloy modification, improved tool concept and optimised processing simultaneously results in a significant improvement of ThF values (+35%) and HCF values (+28%) compared with the KS 1295 standard alloy.

The results of ex-engine testing confirmed the results of in-engine testing. The service life of pistons made from the new alloy was 50 percent longer than the service life of pistons made from the KS 1295 standard alloy.

Local piston bowl edge remelting as a customised solution

In addition to using the new passenger car diesel piston alloy, KS Kolbenschmidt is currently transferring another utility vehicle technology to passenger cars: piston bowl edge remelting.

Piston bowl edge remelting has already become standard for utility vehicle pistons. The development of cracks at the edges of piston bowls is essentially caused by the varied thermal expansion characteristics of different microstructure components within a cast aluminium alloy. For this reason, the structural fineness that can be achieved is very important. The cast structure results from the solidification speeds achieved during casting. Despite ongoing development in material and casting technology it is very hard to fall below the applicable limits.

KS Kolbenschmidt’s solution to the issue was to develop a remelting procedure to apply to cast blanks. In this process, the sections under extreme load on the piston crown are remelted in a controlled manner, followed by completely processing of the piston bowl outline and compression surface. The resulting fine structure that is homogeneous around the remelting sections increases the thermal fatigue characteristics of the critical sections by up to 90% (see Figure 3). The increased process stability in comparison to casting is an additional benefit.

The remelting procedure represents a customised solution that considerably increases the reliability and quality of diesel pistons. Engine testing results from KS Kolbenschmidt and from customers have confirmed the potential of the technology.
Top performance and reduced consumption with passenger car steel pistons

Compared with aluminium pistons, modern steel pistons provide a robust solution solution for future supercharged diesel engines with specific engine performances in excess of 100 kilowatts per litre and ignition pressures beyond 200 bar. The focus during the transition to steel as the piston material lies not only on the realisation of increased performance, but also on the improved thermodynamic efficiency achieved with the steel piston and the potential reduction in friction resulting from a piston design that is geared towards steel materials.

Improvements in fuel consumption and emissions therefore add up to up to 5% depending on the application.

Almost all international car manufacturers are currently testing the passenger car steel piston as part of endurance runs. KS Kolbenschmidt was recently appointed to take charge of series development and the production launch is scheduled for 2014.

The patented KS Kolbenschmidt steel piston design consists of a single-part forged piston with supported ring zone that is characterised by very low groove deformation (Figure 4). With this concept, it is possible to safely comply with more demanding future requirements in terms of gas flow quantity and oil consumption.

LITEKS®-3 lightweight design and reduced friction for petrol engine pistons

Apart from the familiar piston-specific basic requirements, the development of modern petrol engines focuses on topics including reduced friction, increased mechanical and thermal resistance at a reduced piston weight, optimised secondary piston movement and optimised gas and oil sealing functions.
The consistent ongoing development of the LITEKS® piston design up to the current third generation has enabled the weight advantage compared with the standard piston design to be increased to 28%. The new KS 309™ high-performance alloy provided the basis for this enhancement, in connection with further optimised casting technologies and the consistent adaptation of the design to the resulting material-specific benefits.

In order to reduce the weight, we brought casting tool technology to series maturity that represents recesses in the weight pockets of the ring zone for the first time. This technology was successfully launched in series production on the basis of the current LITEKS® design (Figure 5).

The friction output advantage at the skirt of the fired engine for this piston concept was verified by applying the floating-liner testing technology available to KS, and can be up to 46%! This potential is enabled through the implementation of a comprehensive package of measures to reduce friction, such as an asymmetrical definition of the piston skirt widths adequate to withstand the loads applied, reduced axial offset, increased clearance and functional, asymmetrically crowned skirt geometries (Figure 6) as well as the use of the new NANOFRIKS® piston skirt coating. The piston noise response was also verified and showed no disadvantages compared with previous designs.

**NANOFRIKS® – reducing friction and wear**

Modern engines and current piston designs are challenging the tribological load capacities of the piston skirt. The NANOFRIKS® skirt coating, developed by KS Kolbenschmidt to minimise friction and wear, fully complies with said requirements. We were able to apply the latest nanotechnology-related findings to this skirt coating for the first time.

Figure 6: LiteKS® concept with asymmetrically crowned skirt outline on the thrust and anti-thrust side to reduce friction

Figure 7: Floating liner measuring results for the skirt friction of NanofriKS® compared with LofriKS®
Tribometer tests confirm that the NANOFRIKS® coating reduces the dry-friction coefficient and wear by more than 50% compared with standard series coatings. To this end, NANOFRIKS® is setting new standards by featuring an adapted combination of nano particles, binding agents, solid lubricants and additives. NANOFRIKS® therefore sustainably complies with the current customer requirements profile with respect to reduced consumption and high reliability as part of in-engine use (Figure 7). The successful series introduction of NANOFRIKS® at leading car manufacturers around the world emphasises KS Kolbenschmidt’s leading role in piston coating technologies.

STEELTEKS® – second generation of utility vehicle steel pistons for minimum compression heights

Run times are always longest in the truck and transport sector. In addition to the reliability that is necessary for complying with this requirement, the objectives are low emissions, maximum efficiency and hence low fuel consumption.

In contrast to friction-welded steel pistons, the patented Kolbenschmidt STEELTEKS® piston is produced from a single forged part. The development of this special design has enabled Kolbenschmidt to implement a completely new production method for mono block steel pistons.

We are currently working on further developing and extensively testing the STEELTEKS® piston in order to create a second, improved generation of mono block steel pistons.

Figure 8: contact pressure distribution at the pin, rotational speed and friction loss within the piston pin bed in the utility vehicle steel piston module at 1,900 rpm, full load

Contact pressure and deformation of the piston pin at 370 degrees kW (max. gas force)

Upper side in the piston hub

Bottom side in the connecting rod eye
The extremely low compression heights enabled by this piston design amount to less than 50% of the cylinder diameter (Figure 9).

In the same way as for pistons that are friction-welded twice, we were able to transfer the benefits regarding friction, weight, wear and cavitation to this design.

**KS system expertise reduces emissions and fuel consumption**

In recent years, KS Kolbenschmidt has consistently built up expertise in designing, developing and producing systematically optimised piston systems.

We successfully operate a dedicated friction output test bench for passenger car applications that operates according to the floating liner principle in order to integrate the results into areas such as friction simulation.

KS develops complete piston systems for utility vehicles, consisting of pistons, piston rings, cylinders, pins and connecting rods that have been optimised with regard to friction and consumption. On a whole, the piston system optimised by KS Kolbenschmidt is characterised by friction values reduced by up to 18% at a constant, low oil consumption.

The friction at the piston pin represents a further friction component within the piston system. For this reason, KS Kolbenschmidt has determined the friction coefficient between pin, piston and connecting rod for various high-performance material combinations so as to integrate the results into the piston dynamics simulation (Figure 8). Piston pins were also coated and tested with diamond-like carbon (DLC).

Figure 10 illustrates the potential CO\textsubscript{2} savings of the system components within a passenger car diesel engine. The use of steel pistons and the optimisation of additional components within the assembly group allow for CO\textsubscript{2} savings of up to 4.5% compared with current standard aluminium piston systems.

**Figure 9:** STEELTEKS\textsuperscript{®} mono block utility vehicle steel piston design enables minimum compression heights

**Figure 10:** CO\textsubscript{2} savings in a passenger car diesel engine developed in a customer project