KS Aluminum Pistons
for Truck Applications
Requirements

The development of on- and off-highway diesel engines for a wide spectrum of applications is affected by global emission requirements and the minimization of friction losses. The high cylinder pressures and specific powers of modern direct injection diesel engines cause high mechanical and thermal loads. Aluminum pistons with conventional material and cooling gallery are pushed beyond their limits by these increased loads. Fig. 1 shows the application limits of different piston types for light, medium, and heavy duty applications with respect to specific power.

For heavy duty trucks with more than a 2 l displacement per cylinder, a specific power up to 35 KW/l is required. Like passenger car engines, there is an increased trend also with truck engines for “down-sizing” which results in an increased thermal loading of the piston.

Higher peak pressures of over 200 bar and durability requirements of 1.2 million miles are demands of special significance for the development of new aluminum alloys, the local improvement of material properties, and the optimization of piston cooling capacity. More stringent emission control legislation also necessitates measures to reduce friction and fuel consumption.

Piston Design Features

KS Kolbenschmidt aluminum pistons for diesel engines are distinguished by enhanced boss load capacity and directional solidification in the casting process. This is achieved by the consistent use of one-piece core molds and optimum core cooling. Moreover, this approach allows a robust design of the casting molds. The pin boss span is reduced when using a tapered conrod by combination with a curved pin boss inner face, whilst maintaining the necessary clearance at maximum conrod angulation. This allows use of shorter pins and reduction of the oscillating mass. An additional reduction in pin boss span spacing can only be achieved by applying a stepped rod.

When all these design options have been exploited, pin bore bushings can be applied to further increase the load capacity. Fig. 2 shows a modern diesel piston for heavy duty applications with pin bore bushings made from special brass. The fine bore techniques developed by KS permit the use of pin bore profiles inside the bushings that are required for proper functioning of the pin bearing regarding uniform pressure distribution and good lubrication. With this technology, virtually all pin bore profiles and ovality shapes can be superimposed in all required characteristics.

Fig. 1: Capability limits of different piston designs

Fig. 2: Modern KS Aluminum piston with pin bore bushings and hard anodized crown area
As a reinforcement of the top ring groove and occasionally the second groove, highly loaded aluminum diesel pistons are strengthened by a ring carrier made out of an austenitic gray cast iron. The ring carrier and the aluminum base material are bonded by an intermetallic Alfin layer.

The combustion bowl, especially the bowl rim, is another critical zone of today’s highly loaded diesel pistons. The combination of low cycle fatigue (LCF), caused by the cold and hot swings of the engine, and the high cycle fatigue (HCF) mode, resulting from the gas force, can lead to crack initiation at the bowl rim or at the bowl bottom. Engines for on and off highway and marine application are especially subjected to such loading due to thermal cycling.

KS Kolbenschmidt has developed innovative solutions in the areas of piston cooling and materials for these requirements.

**Piston Cooling – DynamiKS®-Improved Heat Transfer by Increased Oil Flow**

Pistons have a ring-shaped cooling cavity that is filled with oil to effectively reduce temperatures. The oil is provided through a nozzle that is installed at the crankcase. The function of the oil is to conduct heat and transport it towards the drain of the cavity. The position and more importantly the shape of the cooling gallery have a significant influence on the temperature distribution in the piston.

KS Kolbenschmidt uses the cutting edge tools for piston design. These include structural finite element analysis and CFD (Computational Fluid Dynamics) to simulate the filling level of the cooling gallery and the oil movement within. This method allows for the optimization of the heat transfer from the piston to the oil, that otherwise would be difficult to analyze. The calculated values are necessary boundary conditions to predict the temperature distribution in the piston and the heat flow within the power cylinder components (see Fig. 3).

New software can visualize oil dynamics over the whole crank cycle. This reveals the complex events, which include various stages of filling, transport in the gallery, and drainage. Consequently, our design engineers can now do virtual testing of new ideas and designs.

The result of these investigations is the development of the DynamiKS® pump gallery (Fig. 4) which takes advantage of the oscillating piston movement in order to increase the oil throughput in the cooling cavity. The unique stepped design, translates a velocity component of the piston into a circumferential movement of the oil during the oscillation.

![Fig. 3: CFD temperature distribution in the cooling](image)

![Fig. 4: KS DynamiKS® cooling gallery](image)
The higher oil flow increases the heat transfer significantly. In comparison to the ContureKS® cooling gallery that has been proven in multiple applications and features a variable cross section, the temperatures at the bowl rim is reduced by 15 °C and at the top ring groove by 10 °C (see Fig. 5).

The reliable and established production technology using lost salt cores can also be used for these complex cooling gallery shapes. The production process for the salt cores and for the piston castings has been optimized.

**New Material**

Although steel pistons are traditionally used for the highest power ratings, there is still a market demand to extend the range of aluminum pistons. Therefore, the new KS alloy V4, has been brought into series production. This alloy fulfills the above mentioned requirements for a higher thermal mechanical (TMF) load bearing capability. A specially developed alloy composition, combined with a specific, process controlled microstructure, which has been adjusted for specific thermal and mechanical piston loads, leads to a significant improvement in the critical temperature range above 300 °C. Fig. 6 shows the improvements accomplished with this alloy in comparison to the established KS 1295+ alloy in special TMF material tests with total expansion prevention. For bowl rim temperatures of 400 °C, the thermal loading capability (TMF) is increased by 86 %.

KS Kolbenschmidt is in the process of developing a new aluminum material specifically for diesel applications to further enhance the thermo-mechanical fatigue strength.

**Local Re-Melting of the Bowl Rim**

The refinement of the microstructure is of critical importance for the mechanism of crack initiation at the bowl rim due to the varying thermal expansion of the different microstructural components within aluminum alloys. In spite of the advancements in foundry technology, there are limits with regards to microstructure for cast alloys. KS Kolbenschmidt has developed a re-melting process that is applied to the pre-machined casting as a solution to this problem.

This process consists of a controlled re-melting in the highly loaded combustion bowl area after pre-machining. The final bowl shape and the compression height are finish-machined afterwards. Fig. 7 shows a cross section of the piston with...
the re-melted bowl rim before final machining. The resulting fine and homogenous microstructure in the re-melted area improves the thermal fatigue properties in the critical range of up to 200% as shown in Fig. 8.

Other advantages are the increased process stability compared to casting and an improved surface quality in machining. The re-melting process is a tailored solution that increases the durability and the quality of diesel pistons significantly. Results from engine tests at KS and at OEMs have confirmed the potential of this technology.

Cavitation

The accumulated damage due to cavitation on the outside of the cylinder liner is the result of a liner vibrational response caused by piston motion. Cavitation sensitivity depends on the design of the cylinder liner and the coolant passages. The impact of the piston motion can be influenced by the guidance of the piston in the bore, i.e. the design of the skirt profile and the skirt elasticity in combination with the choice of pin bore offset.

The design tools applied by KS Kolbenschmidt help to minimize the risk for cavitation. The analysis of the piston motion calculates the vibrational response of the cylinder liner via dynamic piston secondary motion simulation at different load cases of the engine. The command variable for the examination of the simulated vibrational response is the velocity at which the liner reacts to the stimulation of the piston. Fig. 9 shows the cylinder with cavitation damages on the left side and the cylinder after successful optimization of the piston system on the right side. In conclusion, a reduction in cavitation velocity of around 60% was accomplished by changing the piston’s secondary movement.

NanofriKS® – Reduction of Friction and Wear

KS Kolbenschmidt typically applies a LofriKS® 2 coating to the skirts of pistons for diesel engines having cast iron or steel liners. LofriKS® 2 helps the break-in of new engines with regards to increased scuffing resistance, minimized skirt wear, and the creation of favorable hydrodynamic conditions for friction reduction. With escalating peak cylinder pressures and higher side forces at the skirt, the tribological loading of the skirt coating increases. As a solution for this demanding task, Kolbenschmidt engineers are utilizing the most recent research results in Nanotechnology.

![Fig 8: Thermoshock test results of bowl rim with/without local re-melting](image_url)

![Fig 9: Reduced liner vibration to avoid cavitation](image_url)
The resulting new piston coating, NanofriKS®, reduces the dry friction coefficient as well as the wear by approximately 50% (see Fig. 9). With this development, KS Kolbenschmidt has underlined its role as the leader in coating technology.

Summary

With targeted recent developments in the areas of design, materials, coatings, and manufacturing processes, KS Kolbenschmidt has prepared for the future requirements in diesel engines for commercial vehicles. Current series developments and strong market demands for new solutions confirm our strategy.

Outlook

The many good reasons for the continued use of aluminum alloys for truck diesel pistons are driving the development of new design and manufacturing technologies. An aluminum piston is cost effective, offers excellent heat conductivity, low weight, good reliability and is very recycling friendly.

Our future developments will concentrate on solutions for engines with increased power densities and reduced emissions using tools such as material engineering and innovative design for piston and piston cooling. These will be complemented by the new NanofriKS® skirt coating for reduced friction, which has already proven itself under series production condition for gasoline engines.