PISTON RING COATING REDUCES GASOLINE ENGINE FRICTION

Federal-Mogul has developed a coating system for piston rings under the name of Carboglide which decreases wear in highly charged gasoline engines and further reduces friction losses which occur between the ring pack and the cylinder running surface. The tailored composition of the specific layer structure of the carbon-based Carboglide coating in combination with corresponding modified piston ring designs yields a potential to improve fuel efficiency by up to 1.5%.

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REQUIREMENTS

Manufacturers of internal combustion engines continually face the challenge to reduce fuel consumption and emissions by improving engine efficiency. In particular this necessitates a substantial reduction of mechanical frictional losses. The components of the power cylinder and crankshaft drive are at the center of these development efforts. The piston ring pack has a significant potential for bringing down friction losses due to its fairly high (24 %) share of mechanical frictional losses, ❶. At the same time measures such as direct injection and turbocharging among others, which increase engine performance, intensify the requirements for the functional behaviour of piston rings.

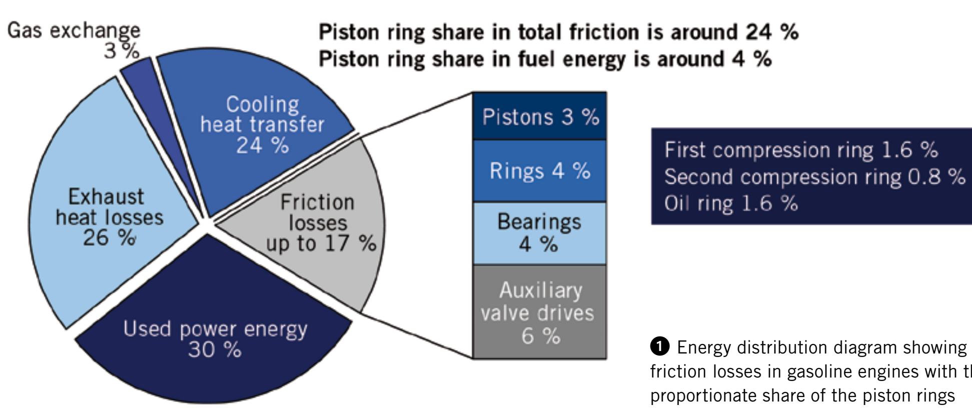
When considering measures to optimise the tribological system of piston ring and cylinder surface, piston ring coatings play an increasingly important role as they can directly influence the wear and friction behaviour and the resulting scuff resistance. By introducing Carboglide Federal-Mogul is providing a coating for piston ring applications which meets the most stringent requirements for functional behaviour and offers a considerable potential to reduce frictional losses.

CARBON-BASED PISTON RING COATINGS

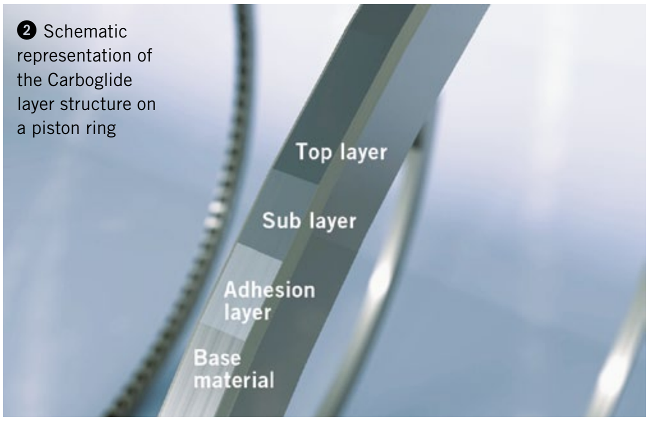
Carbon-based coatings (DLC, Diamond-like Carbon) have a long track record in applications for cutting tools and components that are tailored for the most severe tribological requirements [1]. Diamond-like carbon coatings have only a low tendency for adhesive wear or tribochemical reactions. In most tribological systems these properties result in a lower coefficient of friction under boundary lubricated conditions when the coating is compared to other coating systems (such as metallic layers, hard coatings and others).

Using carbon-based coatings for piston rings necessitated a significant further development of this coating technology to meet the tougher requirements of surface fatigue resistance and coating fatigue. Based on the development of the GOE245 metal-doped, hydrogenated carbon coating the first series application for highly loaded passenger car gasoline engines succeeded in 2006. GOE245 significantly reduced the previously observed cylinder surface scoring which led to scuff-mark formation under the harsh tribological conditions in these AlSi cylinder surface engines. As the damage mechanism is most frequently seen under cold start conditions, this carbon-based coating is typically chosen and used as a running-in coating applied onto a wear resistant coating (nitrided layer, PVD layer) [2].

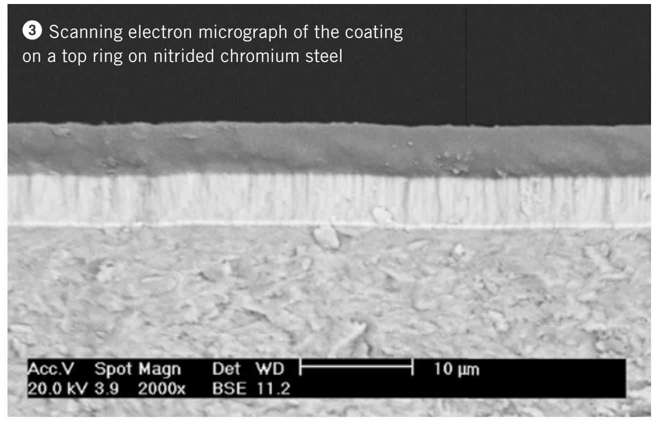
During the subsequent development work the level of coating wear was substantially reduced by introducing the GOE247 coating. This piston ring coating consists of several layers which comprise an amorphous hydrogenated carbon top layer which is applied onto a metal-doped and hydrogenated intermediate carbon layer. The piston ring coating is applied with a layer thickness of 3 to 5 microns and shows a wear resistance in the engine which is higher by a factor of 4 to 5 when compared to the performance of a metal-containing DLC piston ring coating.



❶ Energy distribution diagram showing friction losses in gasoline engines with the proportionate share of the piston rings



❷ Schematic representation of the Carboglide layer structure on a piston ring



❸ Scanning electron micrograph of the coating on a top ring on nitrided chromium steel

COATING STRUCTURE AND PROPERTIES

The combination of direct injection and turbocharging with very smooth cylinder running surfaces, in gasoline engines, significantly increases the demand for piston rings with excellent scuff resistance and low cylinder running surface wear.

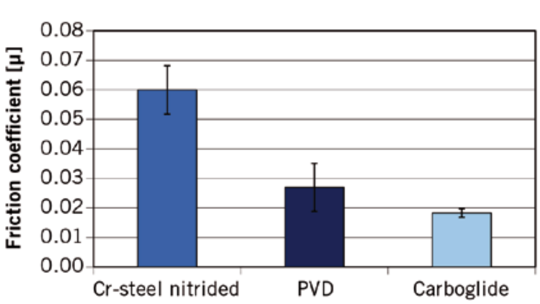
The necessity to reduce fuel consumption and thus CO_2 emissions requires an increasing contribution of the reduction of frictional losses.

In order to meet these tough requirements which translate into very low friction in combination with high wear resistance and superior scuff resistance, a new piston ring coating had to be developed. This was based on Federal-Mogul's application experience with carbon-based piston ring coatings. The new coating, which is known under the Carboglide name, employs a three-layered structure. The coating architecture is characterised by a very thin chromium adhesion layer in the transition zone to the original piston ring surface. This is followed by an intermediate layer and a top layer, ❷. The intermediate layer's structure consists of tungsten- and hydrogenated carbon in which the tungsten carbide is embedded in the form of nanocrystals found in a column-shaped growth pattern. The top layer is an amorphous diamond-like carbon layer which is characterised by a specific ratio of sp2 and sp3 bonded carbon. By adjusting the layer thickness ratio of the top layer to the intermediate layer to a value between 0.7 to 1.5 while adjusting the relation between top layer and total coating thickness to between 0.4 and 0.6 the level of residual coating stress is modified so that the total coating thickness is roughly 10 microns, ❸. Furthermore the high level of coating hardness, measuring between 1800 and 3100 HV0.02, in combination with a coating thickness, which is greater by a factor of 2 to 3 in comparison to conventional DLC coatings, leads to a significantly improved wear resistance of the coating.

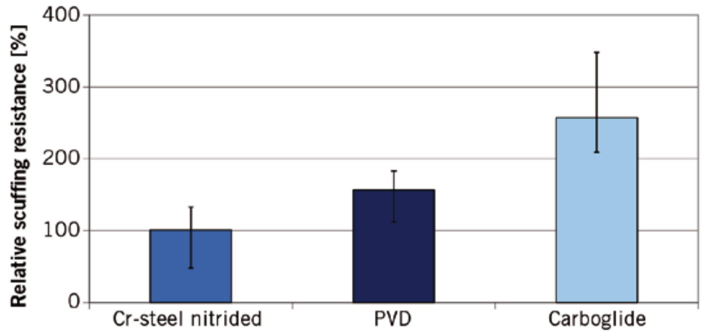
Owed to its layered structure, Carboglide shows excellent friction properties. A comparison with the coefficient of friction of existing piston ring coatings for gasoline engines (nitrided, PVD coatings) clearly shows the potential frictional benefit [3], ❹. In addition to that the tribological behaviour was evaluated under boundary lubrication conditions, using a so-called overload test. The results shown in ❺ demonstrate that the scuff resistance is nearly twice that of a PVD coated piston ring running surface.

FUNCTIONAL BEHAVIOUR DURING ENGINE OPERATION

The beneficial functional behaviour of the new coating was extensively tested under real engine conditions. The first series applications in highly charged gasoline engines demonstrated the durability under "field conditions". The development of a new generation of piston ring coating that serves to significantly reduced frictional losses has been successfully confirmed by coating applications in highly loaded gasoline engines. Frictional loss tests carried out in a fired single cylinder engine with floating liner showed up to 20 % reduction in ring frictional losses using Carboglide in the first and third grooves, ❻. The excellent thermal and chemical durability was confirmed via endurance testing in a highly charged gasoline engine with cast iron cylinder running surfaces and inadequate lubrication levels, ❼. As can be seen, the nitrided steel top ring (first groove) shows strong traces of seizure as well as material



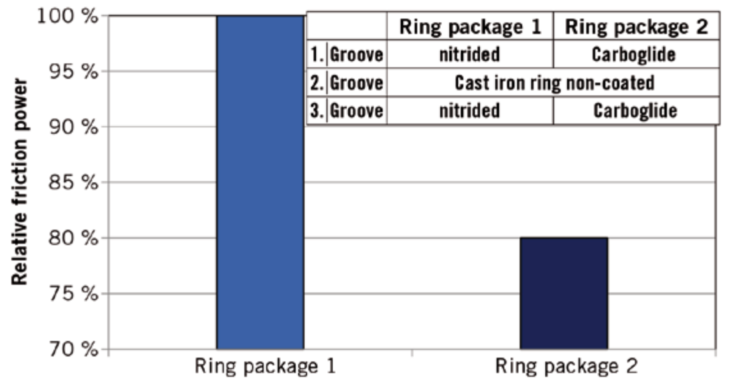
❹ Coefficients of friction of typical gasoline piston ring coatings as measured with an oscillating, vibrating frictional wear tribometer (cast iron cylinder, stroke 30 mm, frequency 10 Hz, normal force 450 N, ester oil lubrication, temperature 190 °C) build-up in combination with cylinder scoring, while the Carboglide piston ring running surface shows a clear uniform wear pattern without any cylinder wall damage occurring. The positive effect becomes particularly evident in evaluating cylinder wear. In cast iron cylinders Carboglide significantly reduces cylinder wear in the top dead center area. Non-engine rig tests confirm a cylinder wear that is lower by a factor of up to 3 compared to PVD coated piston rings.



❺ Relative scuff resistance of nitrided, PVD and Carboglide coated piston rings, (cast iron cylinder, stroke 4 mm, frequency 40 Hz, normal force continuously increasing to 700 N, lubrication Castrol Edge 5W30, temperature 120 °C)

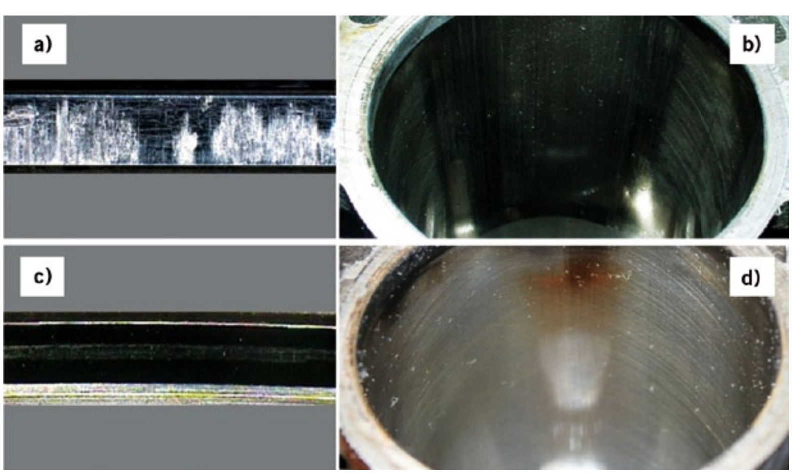
SUMMARY AND OUTLOOK

The new coating coating combines extremely low friction values with high strength and durability of piston rings and cylinder running surfaces. By using this coating, the ring pack's frictional losses can be reduced by up to 20 %. It significantly protects the cylinder running surface against scoring, increased wear and scuffing during inadequate lubrication. Carboglide makes a substantial contribution to the development of high performance gasoline engines with even better fuel economy by up to 1.5 % with consequently lowering CO_2 emissions.



❻ Relative frictional losses of a piston ring package with Carboglide coated top and oil control ring in fired single-cylinder engine in comparison to a conventional nitrided ring pack

Future development work will focus on the combination with the design advantages of LKZ oil control rings addressing both frictional losses and low oil consumption [5]. Due to the low friction and the high wear resistance of Carboglide the combination with LKZ further reduces the frictional losses of the ring pack. Initial customer tests in diesel engines for delivery vans already resulted in a significant reduction of fuel consumption of around 1 % during the New European Drive Cycle. This potential with oil control rings in diesel engines will be examined during further research.



❼ Comparison of the running surfaces of nitrided (a) and Carboglide (c) coated top rings and the corresponding cast iron cylinder running surfaces (b + d) after a 525 h endurance test in a turbocharged gasoline engine

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