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Advances in surface engineering

Newer materials with improved properties can enhance the properties of the working surfaces of cylinder components for the demands of increased temperatures, pressures, and corrosive atmospheres and still satisfy performance and life requirements.

by Dr. R. Mahadevan, India Pistons Ltd.

By all accounts, the internal-combustion engine will continue to play a major role as the prime mover for automotive vehicles for decades to come. It has faced a lot of challenges in the past, but it is also true that at every challenge, the industry comes up with an adequate response to meet that challenge in part or in full.

Higher specific output, tighter emission norms, CO_2 reduction through better fuel economy, longer life, and affordability will remain as persistent demands from the engine designer in the foreseeable future. The order of priority may change, influenced by factors such as fuel and oil prices, state of infrastructure, customer preferences, legislation, resale value, etc.

Central to the response from the component designer to these requirements is the constant search for newer materials with improved properties. Quite often one finds that while the base material meets the strength and durability requirements, the working surface suffers from incompatibility with the mating surface or tends to suffer from irreparable damage leading to failure.

Surface engineering has provided an answer to these deficiencies by enhancing preferentially the properties of the working surface. Cylinder components, which have to bear the brunt of increased temperatures, pressures, and corrosive atmosphere and still satisfy performance and life requirements, have benefited greatly from recent advances in surface engineering.

Surface engineering includes diffusion treatments, overlay coatings, and surface modifications that are primarily aimed at improving wear, corrosion, and scuff resistance, as well as coefficient of friction.

Surface modification and diffusion result in a thin modified layer that has the improved properties, whereas in overlay coatings there is an interface present that distinguishes the coating from the parent material. The reciprocating piston and ring assembly and the corresponding cylinder bores are the best examples of components that have benefited the most from advances in surface engineering.

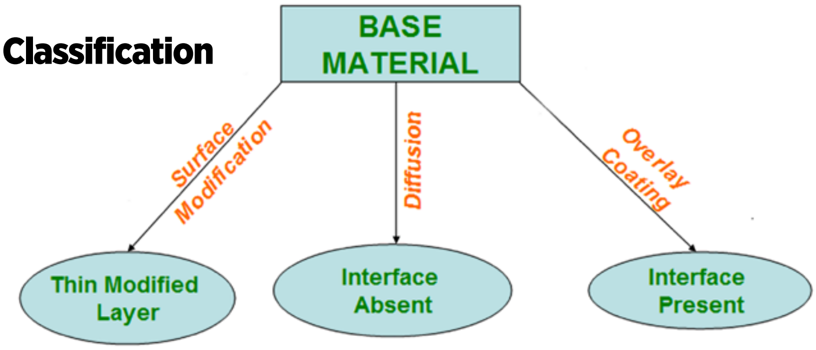
Dry-film coatings

These are generally applied on piston skirts, engine bearings, journals, valves, and pushrod assemblies. These contain molybdenum or tungsten disulphide and provide surface lubricity that protects against friction, galling, and wear. In some cases, they have the ability to hold oil and prevent oil film being pushed out of mating surfaces.

The piston image shows a typical piston whose skirt has been screen printed with a MoS2-containing thin film. Mechanical friction arising from the piston/bore interface is known to decrease over a considerable part of the working life with such coatings. Polymer-based coatings are also being employed as friction-reducing agents subject to their ability to withstand the working temperature.

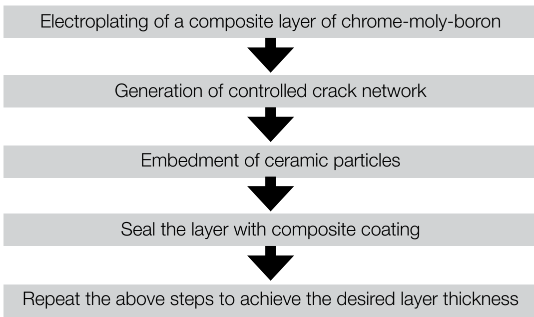
Thermal barriers

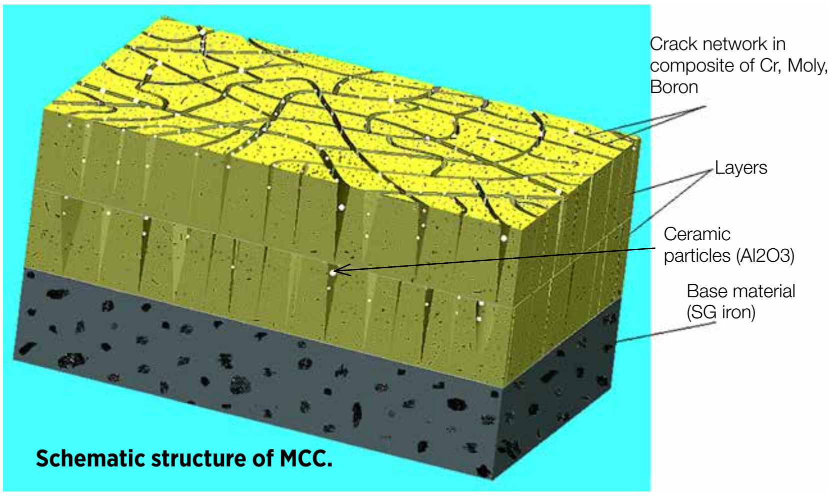
Thermal barriers applied on piston crown and top land, combustion chamber, exhaust valve port, and manifold are coatings generally containing high percentages of ceramic ingredients. These help to reduce heat absorption by the base material of the component and keep the parts operating at a cooler temperature. This area of research received a lot of attention in the past, particularly in the context of



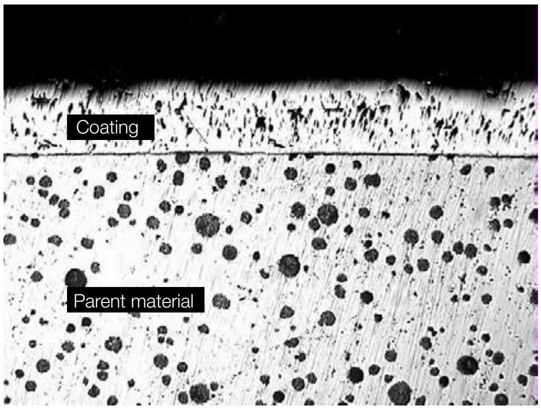
Surface engineering methods.

Process highlights

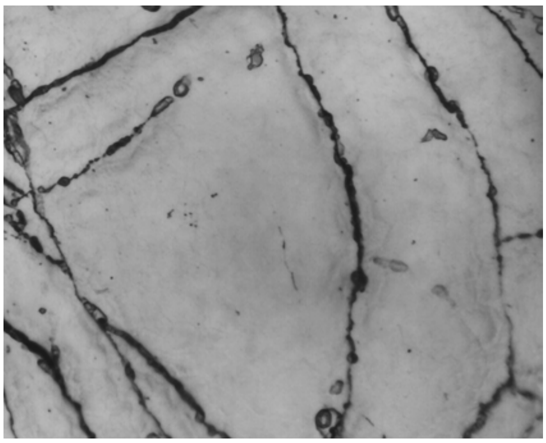




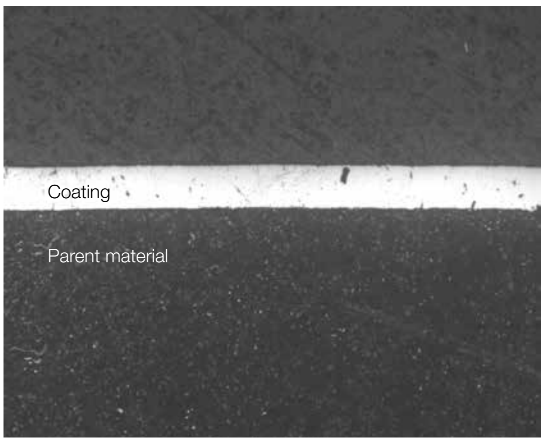
Schematic structure of MCC.



Cross section of MCC at 100c.



NDC coating surface at 1000x.



Typical cross section of NDC at 100x.

adiabatic engines, which later waned due to durability concerns and energy recovery issue.

The piston ring peripheral surface and cylinder bores have received special attention from designers for improvement of their running properties. Heat treatment or surface modification only provides limited solutions. For example, heat treatment of cast iron rings and liners and nitriding of steel rings and steel liners have been employed in heavy-duty diesel engines for improvements in strength and wear resistance. However, surface coatings have now become an integral part of cylinder component design by virtue of the higher hardness and thermal properties one can achieve for improved wear and scuff resistance. Some of these coatings are described below.

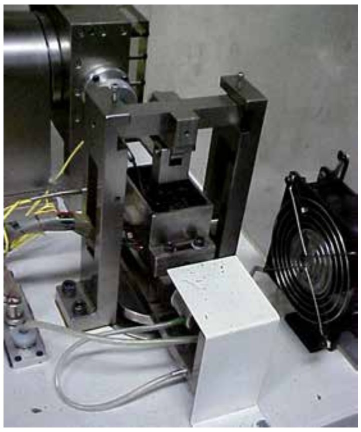
Types of coatings

Hard-chrome plating by electrolysis and molybdenum coating by plasma spraying have been known in the industry for a long time. Hard-chrome plating provides a base reference for wear and scuff resistance against which other coatings are compared. Molybdenum provides exceptionally good scuff resistant surface but suffers somewhat in terms of wear resistance. Plasma spraying, however, provides the flexibility of using a mix of metal powders than can be sprayed to enhance specific properties.

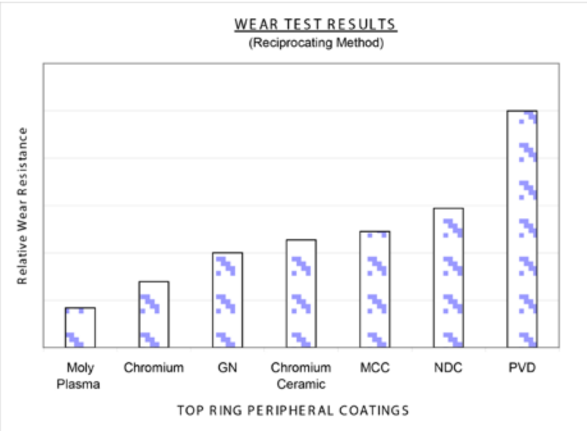
Composite coatings

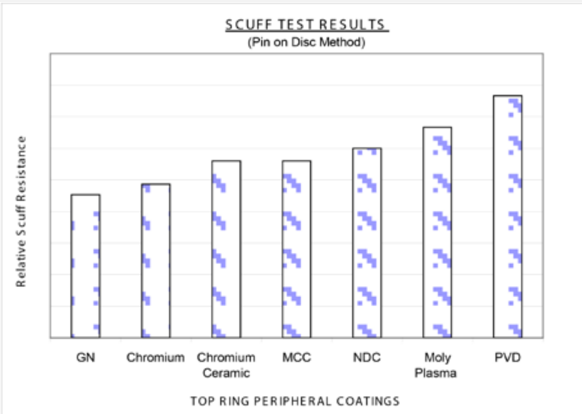
Development of a hard-chrome coating with embedment of ceramic particles (Al2O3) in multiple layers provided the next big step. Major manufacturers of piston rings have their own version of chrome ceramic coatings. A further improvement came along with the development of moly chrome ceramic (MCC) coating with added scuff resistance to the

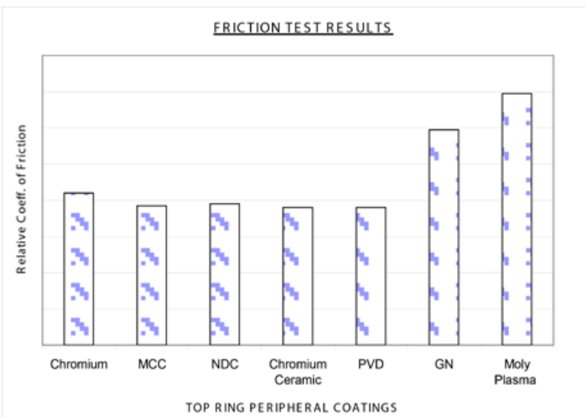
PVD furnace and equipment.



Reciprocating wear and friction monitor.







These bar charts show relative top ring peripheral coating properties, with chrome as a reference.

already high wear resistance. The process essentially is pulse electroplating for which chrome, molybdenum, and boron are co-deposited and ceramic particles are embedded in a specially developed crack pattern in multiple layers.

Diamond coatings

Further improvement in wear resistance of piston rings can be obtained by employing diamond instead of ceramic particles for embedment in specially developed cracks. In a variant of the diamond coating developed by the author's team, nano-diamond particles are co-deposited with chromium and molybdenum by a unique electroplating technology wherein ultra-high dispersion of nano-sized spherical diamond particles are embedded, leading to a highly wear- and corrosion-resistant coating. Multiple layers of such nano-diamond composite (NDC) plating are employed to achieve the desired coating thickness.

Diamond-like carbon coatings (DLC) have been applied to piston pins, piston ring peripheries, and cylinder bores for improving wear resistance. Physical-vapor deposition (PVD), plasma-assisted chemical vapor deposition (CVD), or a combination of both have been employed for applying these amorphous carbon coatings.

Physical-vapor deposition has now provided a method of depositing very hard coatings from the vapor phase onto the surface of piston rings. Very thin coatings, as low as 20 microns of chromium Nitride for instance, can provide exceptionally good wear and scuff resistance with the advantage of lower friction compared to conventional coatings.

Comparison

A specific test rig, in which ring samples with designated coating can be reciprocated at various loads with varying frequency at different temperatures in flooded lubricating conditions, was designed and fabricated for comparing the various coatings. An optical profilometer was used to assess wear figures for relative comparison of wear, scuff, and friction coefficient tested against cast iron plateau honed liner surface.

The accompanying three bar charts show relative properties, with chrome as a reference, and indicate how surface coatings have progressively been developed to meet the requirements.

In conclusion, there are several options that are available to the designer to choose the most appropriate surface engineering methods, which in combination with a standard base material can meet the engine performance requirements. Continuous research is going on in further extending the boundaries of usage of presently known materials with newer surface engineering techniques by way of coatings and surface modification. ■