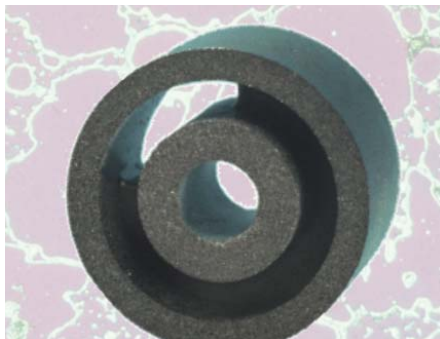


Putting Materials Together

■ *The whole is more than the sum of its parts. Bosch researchers are combining a variety of materials and their properties to provide new, made-to-measure materials. This is not only improving the functionality of existing automobile components but also giving rise to advances, such as in the area of direct diesel injection, that have hitherto been impossible.*

Composite materials are the new marvels being championed by the material science researchers at Bosch. Where in the past metals, ceramics and plastics were used as homogeneous materials, researchers are increasingly combining the properties of these three to form so-called composite materials. Lower weight and reduced wear leading to increased longevity, cheaper components and not least materials with entirely new properties — these are just some of the fruits of the research now being reaped by the scientists and developers at Bosch.

One example is direct diesel injection using the common rail principle. In order to make use of the advantages offered by this fuel injection technology, the timing of the injector operation needs to be extremely precise. The heart of each injector is its magnetic enclosure, inside which the coil for raising the injector needle is wound. If this enclosure was composed of solid iron, unwanted eddies would arise in the material and would delay the switching process. Bosch researchers have avoided this problem by embedding fine particles of iron in plastic to make a composite material. This is achieved by pressing plastic-covered powdered iron and subsequently cross-linking the polymers in the component. The trick in the whole process lies in the combination of materials' properties. The plastic matrix insulates the iron particles from one another and prevents eddy currents. The large quantity of iron ensures the necessary magnetization and rapid transfer of force to the injector needles.



A magnetic enclosure made of a metal-polymer composite (with an optical photomicrograph of its structure in the background) increases the speed of valve switching in an injector system.

For components that are highly susceptible to wear, such as those subject to high frictional forces, Bosch has developed composite materials with a metallic matrix. A ceramic component in the material makes it hard and wear-resistant, while the metallic matrix conducts away the frictional heat thanks to high thermal conductivity. To make the material, powdered ceramic material is pressed to form a substance with open pores, and impregnated with molten aluminum. The resulting material is tailored just for the components, which are much lighter than those made with conventional materials such as steel or cast iron.

Researchers use computer modeling to calculate the "ideal" constitution of a composite material according to its application, determining the relevant properties from this and optimizing the manufacturing techniques for the newly created materials.

Editorial

■ *Dr. Gerhard Benz*
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Development



Made-to-Measure Materials

During the course of the last few decades, composite materials, ceramics and polymers have undergone an enormous increase in importance in comparison with established iron and steel. These "new materials" allow the properties of materials to be largely tailored for an application. In this respect, high-performance ceramic material is truly multi-talented. It is very hard and resistant to wear, corrosion and high temperatures, and its physical properties can be varied across a very wide range.

Composites that include a metallic and a ceramic component open up even more possibilities for this kind of tailoring. This therefore means that soft magnets for fast, high-performance actuators can contain tiny particles of iron within a ceramic surface layer, making them good conductors of magnetic flux while also reducing unwanted eddy currents.

By using thin-layer plasma techniques, ceramic layers can successfully be added to metallic components. This results in outstanding combinations of properties. Examples include high-performance drills coated with titanium nitride, or the friction and wear-resistant carbon-coated parts for fuel injection components. Such "surface engineering" techniques add made-to-measure surfaces to made-to-measure materials, making it possible to produce high-performance composites that exhibit outstanding tribological properties.

Hard Coatings for Highly Stressed Surfaces

■ *Extremely thin coatings are used to make automotive components substantially harder and more resistant to wear. This technology is more important than it might seem at first glance. Bosch researchers and engineers are using sophisticated coating techniques to make components last longer and withstand more demanding applications. The result: vehicles that use less fuel and produce lower emissions.*

Here's the prize question: What do emission standards — which will become more stringent in 2005 (Euro IV) — have to do with the surface coatings on certain components of a fuel injection pump? Materials scientists at Bosch have now come up with some answers: New requirements for lower emissions from gasoline and diesel engines require design approaches that result in ever increasing injection pressures. And to ensure that components such as pump plungers can withstand such extreme stresses, their surfaces are finished using application-specific surface techniques. This is necessary because conventional materials are gradually approaching their limits in terms of tensile strength, wear resistance, hardness and abrasion resistance.

Bosch researchers and development engineers have become highly proficient in surface engineering — the development of new, tailor-made surface materials whose properties and production techniques are specially attuned to specific applications. The goal is to fine-tune the surface properties independently of those of the component's bulk material. This approach offers several advantages: The bulk material can be optimized for the manufacturing process of the component. It can be selected for easy processing in volume production, appropriate intrinsic hardness, and economy in procurement. The applied surface layer, on the other hand, can be optimized to withstand the required contact with the immediate environment and must be both dense and corrosion-resistant, as well as low-friction and wear resistant.

Extremely hard, highly alloyed steel for instance is difficult to machine. That's why engineers resort to a more economical bulk material that is easier to work with and can be supplied with a highly functional surface through surface engineering. For instance the surface of the pump plunger in the pump-nozzle unit of a diesel injection system is subjected to extremely high stresses.

Surfaces are subjected to pressures of more than 2,000 bars and must be free of leaks, which calls for exceedingly precise fits. The surfaces of the pump plunger and the opposing body must slide over one another perfectly, without any wear or abrasion. It is vital for surfaces to be extremely hard and robust, and only few materials can meet these requirements. Bosch researchers are therefore focusing not only on conventional hard coatings such as titanium nitride, but also on diamond-like carbon (DLC). This form of carbon falls somewhere between graphite and real diamond.

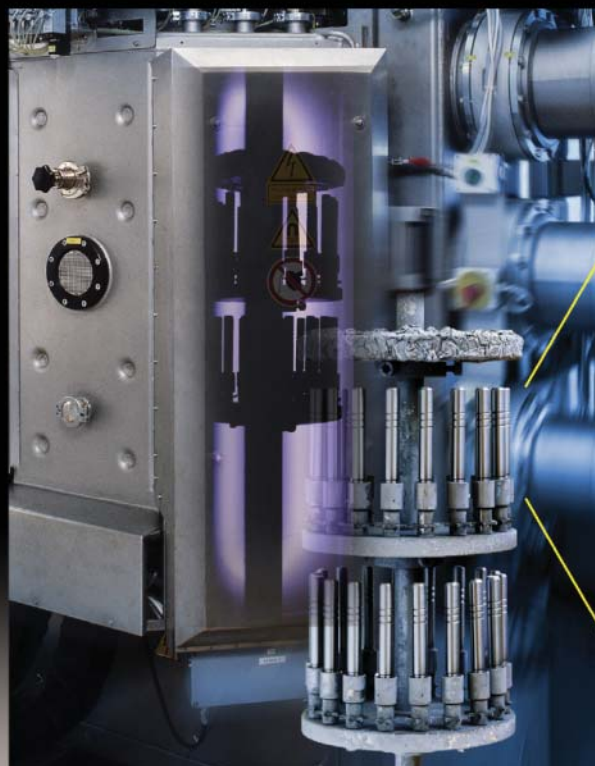
Its hardness far exceeds that of conventional materials, even though it doesn't quite match up to a diamond's Vickers hardness (HV) of 8,000. With a HV of 3,500 to 4,000, DLC is substantially harder than the conventional hard coatings such as titanium nitride, titanium-aluminum nitride and titanium chromide. Stainless steel, on the other hand, has a HV of less than 900. Another advantage of the DLC coating is that it also provides excellent tribological characteristics similar to those of graphite.

DLC is therefore the best surface material currently available for high-precision,

Tailor-Made Surfaces

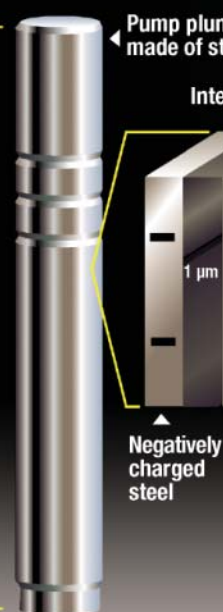
Plasma coating system

Robust and wear-resistant: Process parameters are optimized to fine-tune the surface (here a pump plunger) for the requirements of the application.



Ion bombardment electric field

The flux density and electric field determine the cross-section of the carbon coating.



highly stressed mechanical components. However, to exploit this advantage, there are other process engineering obstacles which must first be overcome. Since many steel materials lose their intrinsic hardness at temperatures above 250 degrees Celsius, chemical vapor deposition (CVD), which is often used for depositing diamond layers, is out of the question, as it requires temperatures higher than 800 degrees Celsius. But Bosch researchers have now found a solution in a plasma-based process which doesn't overheat the components.

Plasma-based coating makes it possible to precisely adjust the properties of the coating material. Gas molecules are dissociated into their carbon and hydrogen components within a plasma. An electric field is applied to bombard the surface of the workpiece with carbon ions. The flux density and energy level of these ions are only two of the parameters that influence the properties of the layer to be deposited. Incorporation of hydrogen into the layer is inevitable. Its presence is the reason why the coatings are unstable above 350 degrees Celsius. But since such high temperatures are not encountered in actual use, this



Wear test of a thin DLC layer.

doesn't present a problem. The advantages of the ion bombardment are obvious: The DLC coatings are very dense and therefore very hard and suitable for applications that require extremely high wear resistance. What's more, the Bosch researchers have optimized the plasma coating process for high production throughputs.

Given the extensive expertise which Bosch materials scientists have accumulated concerning very hard and wear-resistant surfaces, it's a good idea to involve them early in the development aspect of new components. The design engineer defines the requirements the materials and surfaces will have to meet. Which stresses are generated – for instance between the pump plungers and cylinders or between the cams and the tappets? By making a precise analysis of all parameters in such friction pairs and in model-based wear tests, the scientists and engineers collect the information they need to create the required customized surfaces.

A device known as a pin-on-disk tribometer is often used in wear tests: As shown in the illustration (top, right), a pin or a small sphere is forcefully pressed against a rotating disk. If both opposing parts are made of untreated steel, the sphere is abraded at the point of contact, and a circular abrasion track is scored in the disk. If the disk is coated with a thin layer of DLC, not only is the wear on the disk reduced substantially, but the wear on the sphere or

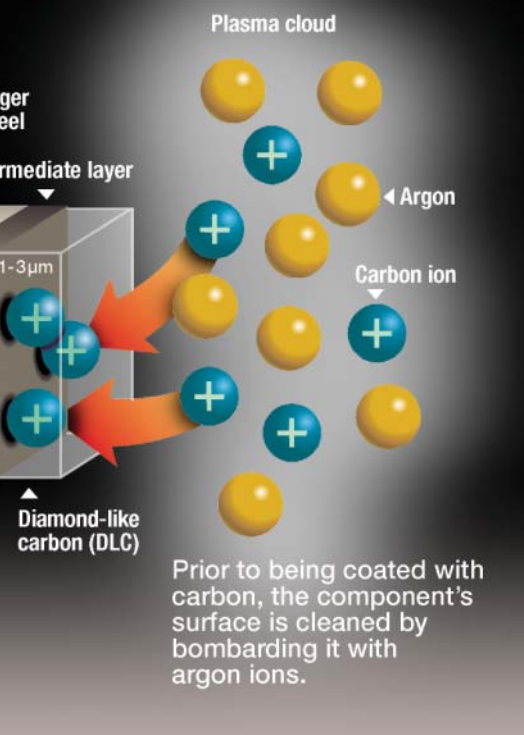
pin is too, even though the latter hasn't been coated. According to the experts, this phenomenon, known as "reduced opposing-body wear" is an important advantage of DLC layers. In a high-pressure pump for instance, coating only the plunger will also protect the inner surface of the cylinder.

Other chemical elements can be incorporated in order to fine-tune the chemical composition of DLC coatings to suit specific applications. The use of metals, for instance, improves the elasticity, toughness and conductivity of the layer in question. To produce this kind of coating, a metal cathode is bombarded with argon ions to create free metal ions, which then become embedded in the DLC layer.

Such technical advances in wear-resistant coatings enable Bosch researchers to keep improving the service life and reliability of many components despite exposure to increasingly stressful conditions. Materials science and advanced coating techniques are therefore vital tools for the designer of high-performance, fuel-saving automotive engines using gasoline or diesel injection.

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Hard as Diamond

■ *Diamond-like carbon (DLC)*

DLC layers aren't quite as hard as diamond but they are hard enough to compare favorably with conventional layers of hard materials (TiN, CrN). What's more, they have the tribological properties of a lubricated surface and are chemically very stable. A plasma process can be used to deposit DLC coatings on workpiece surfaces. Due to their superior properties such coatings are suitable for a wide range of industrial applications, from precise and highly stress-resistant automotive components to extremely thin protective films on hard disks for data storage.

X-Ray Light on Coating Structures

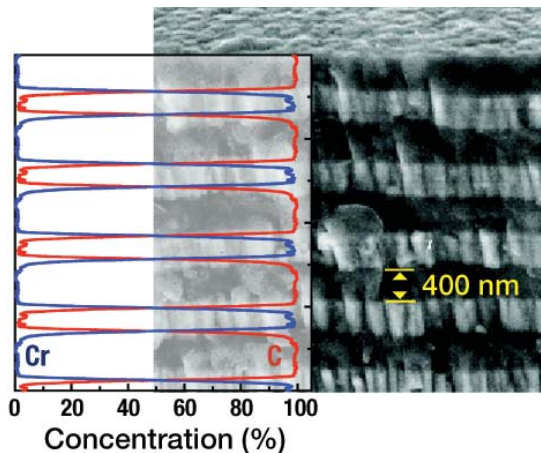
■ *Bosch researchers are using advanced analytical techniques to study the heart of bulk materials and protective coatings as well as what holds them together. The results help engineers create more robust, longer-lasting products.*

Without the advanced methods of chemical and physical surface analysis, research scientists and engineers involved in developing new materials and coatings would be navigating pretty much in the dark: New materials might work as intended, but no one would understand the reason why. Analytical methods are designed to bring light into the dark by characterizing the materials and by exploring the parameters necessary to understand their properties. What are their chemical compositions? Are the boundaries between layers distinct or do materials intermingle and react chemically with each other? Of particular importance is the way layers grow. If unstable intermediate layers are formed, there is the risk of an “eggshell effect”: The layers may flake off. Are any cracks formed? Are different crystalline phases present? What is the effect of the material’s crystallite size?

Bringing light into the darkness – that’s quite literally what Bosch scientists are doing. More specifically, they are using X-rays of varying energies to “illuminate” materials as they push forward their investigation to study ever smaller dimensions. Electron spectroscopy for chemical analysis (ESCA), also known as X-ray photoelectron spectroscopy (XPS) enables them to analyze the chemical composition of layers just three nanometers (millionths of a millimeter) in thickness, both qualitatively and quantitatively. In this imaging method, X-rays irradiate a surface to release electrons – referred to as photoelectrons. The ‘characteristic’ energy levels of these electrons can be used to identify the chemical elements in the surface. A depth of three nanometers corresponds to a layer about 10 atoms thick. Information about greater depths can be obtained by bombarding the superficial atomic layers with ions to ablate them (a process called sputtering), then using ESCA to analyze the next, now accessible layer. This information is vital especially in depth-profiling of wear-

resistant multilayer coatings. Coating systems with special wear- and corrosion-resistant properties such as carbon/chrome or titanium aluminum nitride/chrome nitride can be successfully analyzed using this technique. The results of such analyses are useful in optimizing coatings to suit specific applications and ensure precise layer growth with sharply defined boundaries.

But no single method can provide all the answers. Bosch materials scientists are par-



Depth profiling by means of ESCA analysis (left) reveals the chemical structure of the C/Cr wear-resistant layer shown in the electron micrograph.

ticularly expert at choosing suitable combinations of relevant analytical methods. For example, they use X-ray diffraction (XRD) to more accurately determine the nature of the chemical bonds in the layer, in addition to its elementary composition. XRD can reveal not only whether titanium is present in its metallic form or as a nitride; it can also show which of the many titanium nitrides is present. The method can even determine the crystallite size in the nanometer range.

The spatial structure of a layer – for instance, the internal grain structure or the surface topography – also plays an important role in determining its function. These characteristics are measured by means of an electron microscope or a scanning force microscope. A combination of several analytical methods is usually necessary to obtain a correct description of the material sample and thus a basis for improving the material’s properties.

In Brief

■ *Data bus to maximize safety*

Since June 2001, Bosch has been a member of the FlexRay consortium for the development and standardization of a high-speed data bus system for safety-critical applications. Typical applications of FlexRay are X-By-Wire systems and integrated chassis management. The other partners in the consortium are DaimlerChrysler, BMW, General Motors, Motorola and Philips. The Department of Information and Systems Technology in Corporate Research and Development is coordinating the activities within Bosch and represents the company’s interests in the consortium.

Dates

■ *January 28 – 29, 2002*

Gael le Hen and Roberto Sorito will present a paper on “Digital Mock-Up Based Cooperation at Bosch – Ideas and Concepts for Future Methods of Working” at the “Collaborative Engineering” conference in Stuttgart, Germany.

■ *March 11 – 12, 2002*

“Magnetic Distance and Angle Sensors in Automotive Technology – Principles and Applications” is the theme of Klaus Marx, Anton Dukat, Franz Jost, Hartmut Kittel and Henrik Siegle at the ITG Congress on Sensors and Measurement Systems in Ludwigsburg, Germany.

Masthead

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