DLC Coatings for Increased Wear Resistance

By Mark Boghe

Bekaert Advanced Coatings outlines how “diamond-like coatings” reduce frictional losses in the components that are critical to drive train systems.
An increasing number of DLC coatings have been brought to market in recent years. The main reason for the success of these “diamond-like coatings” (DLC) is the fact that they combine several exceptional qualities. DLC coatings are inherently self-lubricating and resistant to abrasive, adhesive, and corrosive wear.

DLC coatings are a family of coatings made up primarily of carbon chains in an amorphous structure with sp² (trigonal) and sp³ (tetrahedral) bondings (fig. 1). Sp³ is the cubic form of carbon known as diamond, compared to sp² that is graphite. There are different types of DLC: hydrogen-free (a-C), hydrogenated (a-C:H), or metal-doped (Me-C:H) coatings. These coatings are typically thin-film and are applied during a vacuum deposition process (PVD or CVD).

No other single surface treatment offers this unique combination of properties. Possessing a low coefficient of friction and a low surface energy approaching that of Teflon®, DLC has a hardness greater than that of carbide or chromium nitride (CrN). The result is a coating solution that provides a combination of unique wear and low friction. Depending on the deposition technology used, it can be possible to deposit very smooth coatings, exactly reproducing the surface roughness present prior to coating. DLC coatings are typically characterized by the following properties:

- High hardness, up to 20 GPa (measured by nano-indentation) with the possibility to tailor this hardness as a function of the requirements of the application. This high hardness guarantees a high abrasive wear resistance;
- Good adhesion, better than HF2 following the VDI 3198 norm and a critical value (Lc2) exceeding 25 N in the scratch test (coating deposited on M2 steel for both tests);
- The temperature during the process is between 200°C and 350°C, depending on the application and the component material, in order to avoid loss of parts hardness and distortions of parts;
The typical thickness value is between 1 and 5 µm with a spreading of 15 percent; no impact on the original surface roughness.

Besides the properties mentioned here, DLC coatings show very good coefficient of friction values. The DLC coating for the high volume market developed by Bekaert on the basis of its racing experience, Dylyn® Plus, presents a unique, very low coefficient of friction in dry as well as in lubricated conditions. The ball-on-disc (BOD) test allows the determination and the study of the coefficient of friction with varying time, contact pressure, velocity, temperature, humidity, and lubrication factors. Compared to uncoated substrates or to other coatings such as TiN or CrN or other commercial DLC coatings, Dylyn Plus has the lowest available coefficient of friction of about 0.05, remaining low in combination with different lubricants (fig. 2). The results of the BOD tests were confirmed in real engine tests.

In dry conditions the effect of the low coefficient of friction of Dylyn Plus is obvious, but this is not applicable for engine components. In full film lubrication conditions, the effect of the coating is as negligible as that of all the other coatings. But in the boundary or mixed lubrication regimes, as happens for example at a low engine speeds range for valve train components, the decrease of friction from the use of Dylyn Plus is effective.

**BENEFITS TO ENGINE PARTS**

Dylyn Plus is produced on Bekaert’s proprietary large-scale equipment (vacuum vessel larger than 3 m³ for example)
Bekaert can provide DLC solutions for the following applications:

- Automotive;
- Drive train;
- Valve train components—due to the low coefficient of friction, Dylyn Plus reduces frictional losses and increases the lifetime of valve train components, i.e. camshafts, lifters/tappets, finger followers, valves, retainers;
- Piston rings—the high wear resistance of Dylyn Plus coatings in cold welding areas leads to an extended lifetime and an increased reliability of components;
- Wrist pins—Dylyn Plus helps to reduce galling and improves lifetime performance;
- Gears;
- Fuel injection and pump components.

**Fig. 2:** Test results under different conditions.

**Fig. 3:** Coated camshafts.

**Fig. 4:** Reduction friction results.
resulting in a high and reproducible quality at a very low cost. Dylyn Plus is therefore well adapted to help the engineer to reduce mechanical friction losses in combustion engines. The focus is first on the valve train components.

Several tests have been conducted to demonstrate the impact on frictional losses in different valve trains. Components like tappets, camshafts and finger followers have been coated with Dylyn Plus (fig. 3).

In these tests, conducted on an electrically-driven test rig (fig. 5), the torque needed to drive the valve train at a certain speed is measured in different configurations. A reference measurement is made with the original cylinder head. Then, after the replacement of some components with coated components, the measurements are repeated. A

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One can observe an average 25 percent reduction of torque by coating the finger followers, with even greater improvements at lower rpm rates (exceeding 30 percent friction reduction). Coating the camshafts in this configuration will typically reduce the overall friction with an additional 10 percent.

Tests with coated tappets show similar results: an average reduction of 15 percent of the torque but a bigger improvement in the lower rpm range.

Besides the reduction of frictional losses as described above, the use of coatings on valve train components also enables car manufacturers to eliminate wear problems. With increasing combustion pressures, EGR systems, suit contamination and new oils, valve train components are increasingly exposed to very harsh conditions that lead to premature wear. The combination of the low coefficient of friction combined with the high hardness to be found in DLC coatings offers an interesting answer to wear problems. Endurance tests prove that DLC coatings form lifelong solutions for these difficulties.

**CONCLUSIONS**

The application of a tribological coating such as Dylyn Plus offers the possibility to reduce frictional losses in the valve train system. Besides the valve train there are other parts of the engine where these coatings could help reduce the frictions; e.g. the piston assembly and other components that benefit from these properties such as gears. One could even consider the use of lighter materials to decrease the moving mass, and thus reduce friction and fuel consumption. Here again, the wear resistance and low friction properties of the coating are the key parameters.

In any case it is necessary to consider the use of DLC coatings at the beginning of the development phase. In order to achieve a successful design, the substrate has to be selected in relation to the function of the coating. Parameters such as substrate material, heat treatment and surface roughness, are essential factors enabling the coating to reach its maximum performance.