

Friction Behavior of Different DLC Coatings by using Various Kinds of Oil

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ABSTRACT

The requirements on engine components are becoming tougher. On the one hand, the load of the components is increasing due to the optimization of the engines to make them more efficient. New materials and/or coatings and surface treatments are needed to fulfill the new requirements. On the other hand, changes of oil additives and the introduction of alternative fuels are challenging the engine materials as well. In addition, there is a high demand to reduce the friction of the engine for improved fuel consumption. One way to support this is the application of friction reduced coatings and/or surface treatments. DLC coatings seem to be a promising candidate. But what differentiates DLC coatings on the market and within different lubrication conditions in regards to friction?

Standard valve train bucket tappets coated with different DLC coatings will be compared regarding friction to uncoated steel bucket tappets by using a special self build test rig.

The friction results of the test in the lab will be compared to those of the cylinder head tests.

Further the structure of the DLC coatings and the chemistry of the oils will be discussed.

INTRODUCTION

One of the major challenges for the automotive industry is meeting the emission legislative requirements. This is also driven by the customer demand on reduced fuel

consuming cars. The main concept to reduce the fuel consumption is the decreasing of the overall weight of the car. As we know the cars are constantly increasing in weight over the last few years. This results in the increased safety and comfort demands on the car. The use of new materials and the better understanding of materials for a more effective use of them are overcoming a bigger weight increase. The other trend is the development of more efficient engines for reduced fuel consumption. One way to make engines more effective is the reduction of friction within the engine. Reducing mass of components can decrease the friction due to reduced dynamical load. Using lighter materials or better designs for moving components mainly does this. The other way is the use of special coatings and/or surface treatments for reduced friction. Suppliers are offering different coating systems with promising friction reduction properties. The following investigation characterizes different DLC coatings and surface treatment technologies regarding their potential to reduce friction and wear under lubricated conditions. These are basic investigations and can be used as a pre-selection for different engine components. By selecting one specific application like the valvetrain system the reduced friction within the valvetrain can be an enabler for using a more and more cost effective direct mechanical bucket tappet valvetrain system (DAMB). In Figure 1 the general distribution of friction within the combustion engine is shown. It is obvious that the friction contribution of the valvetrain is playing a important role [1].

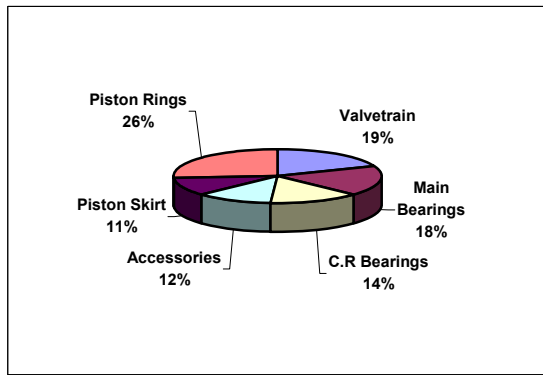


Figure 1 General friction distribution within internal combustion engine [1]

MAIN SECTION

TEST MATERIAL –

Oil

The automotive industry is using specially designed engine oils depending on what local demand dictates. The quality and the chemical composition of these oils are different between the American, European and Asia market. Specific domestic environmental legations also effect the oil composition.

In the lubricant oil industry, additives serve to improve a wide range of features. The list off different types is long: Antioxidants, Detergents, Dispersants, Friction Modifiers (FM), Anti-Wear (AW) and Extreme Pressure (EP) additives. AW and EP additives are intended to operate when the lubrication is poor. Anti-wear and extreme pressure additives usually contain sulfur, phosphorus, boron and zinc or a combination thereof. As understood from their name, the AW additives are aimed to lowering the wear rate by forming a tribofilm which protects the underlying component material. A typical anti wear additive is ZDDP (zinc dialkyl dithio phosphate) which is probably most widely used in formulated engine oils. It also acts as a corrosion inhibitor and antioxidant. The tribo films are formed by the heat due to the friction when the components are in sliding contact. Under extreme pressure conditions, the performance of AW additives becomes insufficient and EP additives are required. ZDDP starts decomposing at 130-170 °C [5].

EP additives are activated in situations when the local pressure is high enough so that microscopic welding between the surface peaks can occur. Also EP additives form a tribofilm with easy shearing properties. EP additives typically contain organic sulfur, phosphorus or chlorine compounds which chemically react with the metal surface under high pressure conditions. Under

such conditions, small irregularities on the sliding surfaces cause localized flashes of high temperature (300-1000 °C), without significant increase of the average surface temperature. The chemical reaction between the additives and the surface is confined to this area [5].

A typical friction modifier (FM) is molybdenum (MoDTC). FM additives work within lubrication conditions. These active agents lower the friction due to the formation of a film. This separates the moving parts from each other. FM additives are different from AW and EP additives due to formation of a film through physical adsorption, instead of a chemical reaction [3, 5, 6]

Five different oils were tested. The specifications are listed in the Table 1 below.

Table 1: investigated oils

	0	A	B	C	B-used
Classification		5W-20	5W-30	0W-30	5W-30
dynamic viscosity 40°C [mm ² /s]	4.46	47.2	57.6	40.2	
100°C [mm ² /s]		8.68	9.72	8.57	
Additives	[content]				
Mo	no additives	low	med	high	like B + dirt from engine test
S		med	high	med	
P		low	high	med	
Zn		low	med	high	
Mg		med	high	low	
Ca		low	med	high	
B		high	low	low	

The chemistry is different between the five oils. These oils are first fill factory oils for the American, European and for the Asia market. These oils have a similar amount of phosphorus, zinc, magnesium and boron.

The oil-0 is additive free and further more this oil has a very low dynamic viscosity at 40°C. The value is nearly ten times lower compared to the other oils. Lowering the viscosity of engine oil is effective in reducing the fluid friction. A low viscosity additionally reduces the oil film thickness [3].

It is known that friction modifier additives have a limited life due to oxidation and thermal instability [2]. Because of this, in addition to fresh oils, the friction behavior of used oil was tested with. This oil runs for 40.000 miles in a test car.

Amorphous carbon coatings, a-C:H or (DLC coatings)

Carbon based coatings are among the most promising surface treatments which reduce friction and wear in sliding contact. Such coatings can be produced by Physical Vapour Deposition (PVD) and Chemical Vapour Deposition (CVD). The CVD method is often a high temperature process, above 300°C. Therefore this process is unfavorable for steel components as they become annealed at elevated temperatures. The PVD process works at low temperature, less than 250°C and is therefore suitable for coating steel components. Carbon coatings are often a mixture of graphite and diamond bonds, hence such coatings are often referred to as Diamond-Like-carbon or DLC.

a-C:H coatings are known as inert coatings with a low surface energy, due to its inactive chemical property [4]. The amount of hydrogen can be controlled by the coating process and is typically in the range of 3 to 40 at%. However, the addition of metal (like W or Ti) or non metal (like F or Si) atoms into the carbon matrix cause changes in chemical and mechanical properties of a-C:H coatings. The amount of metal atoms can vary between 3 and 40 at%. A suitable quantity of non metal atoms is from 1 to 20 at%. The chemical composition depends on the application.

The hardness is affected when the carbon matrix is doped and the ability to react with the environment is improved. The range of reachable hardness is wide. It depends of the amount of hydrogen, the coating process and if the carbon matrix is doped with other elements. Typical values for the hardness are 7 to 40 GPa. The modulus of elasticity is in the range of 25 to 400 GPa. The coating thickness is usually between 2- 5 µm. To get sufficient adhesion to the base material, different types of interlayers are applied. The maximum of heat resistance is between 400 and 500°C.

Test samples

The aim of this investigation was to analyze the influence of different DLC coatings on bucket tappets (16MnCr5 deep drawn material) within different oil grades. For this we have used 3 different DLC coatings from 3 different suppliers. As it is shown in Figure 2 the surface roughness of all received DLC coated parts is very low in comparison to the standard bucket tappet. Therefore, a set of bucket tappets was polished in order to achieve a similar surface roughness like the DLC surface.

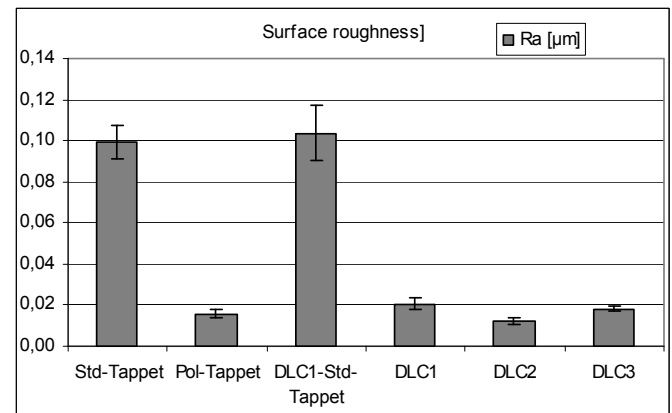


Figure 2: Surface roughness of investigated samples

A good overview how much the surface differs between DLC coated samples with and without a polishing in advance of the coating process is demonstrated in Figure 3.

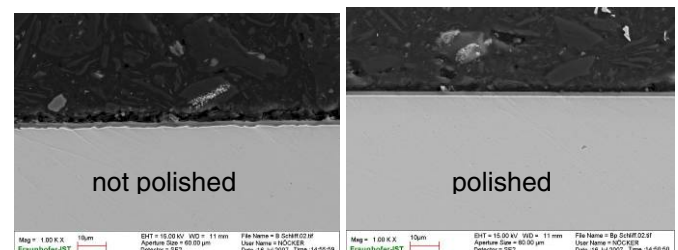


Figure 3: Difference between a polished and an unpolished surface

Characterization of the coating

The coating thickness and coating structure were analyzed by SEM technique. The topography, hardness and modulus were analyzed with a Nanoindenter (Hysitron, Berkovich indenter, tip radius 0.4µm). The Si amount was detected by EPMA. The results of these investigations are shown in Table 2.

	Coating DLC1	Coating DLC2	Coating DLC3
Coating / thickness	a-C:H / 1.5 µm	a-C:H:Si 1.5 µm	a-C:H 1.2 µm
Interlayer	Ti / 0.3 µm	W / 1 µm; Cr / 0.5 µm	W / 1µm/; Cr / 0.5 µm
Roughness Ra	0.021 µm	0.015 µm	0.018 µm
Hardness	16 ± 2 GPa	14 ± 1 GPa	17±2GPa
Modulus	113±10GPa	125±9 GPa	162±22GPa

Table 2: coating properties