**ISSN:** 1231-4005
**e-ISSN:** 2354-0133
**DOI:** 10.5604/12314005.1168493

# REVIEW OF POSSIBILITIES OF INCREASING THE THICKNESS OF AN ANTI-WEAR COATING ON PISTON RINGS BY USING SPECIFICALLY DESIGNED PHYSICAL VAPOUR DEPOSITION PROCESS

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***Abstract***

*The super-hard, anti-wear amorphic coatings based on carbon-like diamond (called DLC) show a promising direction in automotive industry, mainly in terms of decreasing friction coefficient in parts of internal combustion engine. However, the technology of producing DLC-coated parts, which is most often chemical vapour deposition (CVD) or physical vapour deposition (PVD) is proven to be still not perfect for achieving desired characteristics of the coating. The thickness of a coating is the main issue one should strive to improve, as the PVD methods produce films as thin as few micrometres. In such case, the coating is not only exposed to cracking, but also pitting is possible to happen. This is proven to be highly undesirable and unacceptable for this process. In addition, in case of thin films, the adhesion to the base is often too weak, despite the coating itself being extremely durable and hard. In this article, a theoretical ways to improve the process of coating are presented. The process itself is described, the achievable parameters are defined and the possible improvements are stated. The research made for the purpose of this article will be further exploited to design a process allowing creating the coating for testing of the best possible characteristics.*

***Keywords:*** *coatings, anti-wear, internal combustion engine, PVD, CVD, thickness, DLC*

## 1. Introduction

The main advantages of DLC coatings are widely known to be excellent tribological proprieties, strong wear resistance, high hardness and overall good mechanical characteristics. The main problem with DLC coatings however is their poor uniformity in terms of thickness and weak adhesion to the base material. Those issues complicate possibilities of using DLC in industrial applications.

To better understand the importance of increased thickness, one can assume that the mechanism of wear of a coating is strictly dependent of its physical structure. In Fig. 1, the process of scratching and cracking of both thick and thin films is shown. If the coating is thick, the cracking usually does not go through its entire thickness. For thin coatings however, the cracking move faster, a delamination of a coating is possible and overall, the film may be destroyed relatively faster with the same stress applied.

## 2. DLC coatings – basic information

DLC coatings are divided into groups by their hydrogen content and also by their $sp^2/sp^3$ bonds ratio. As shown in Fig. 2, amorphous coatings (most widely used for high performance tasks, for example in automotive industry) are located in the lower left corner. Right corner contains coatings with more hydrogen in their structure.

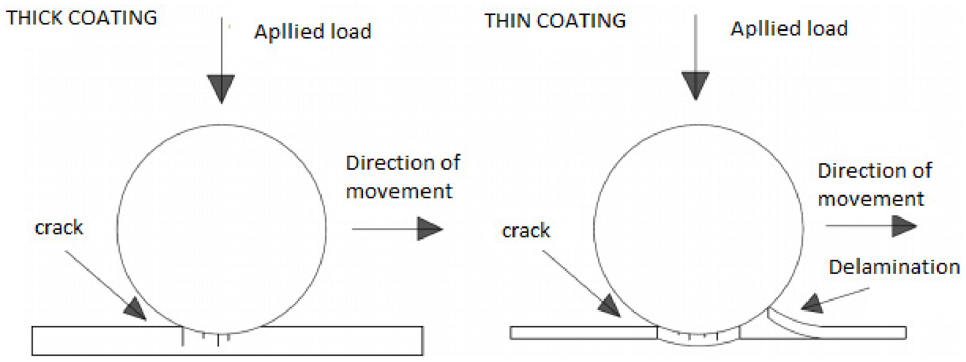



*Fig. 1. Cracking of a coating in dependence of its thickness*

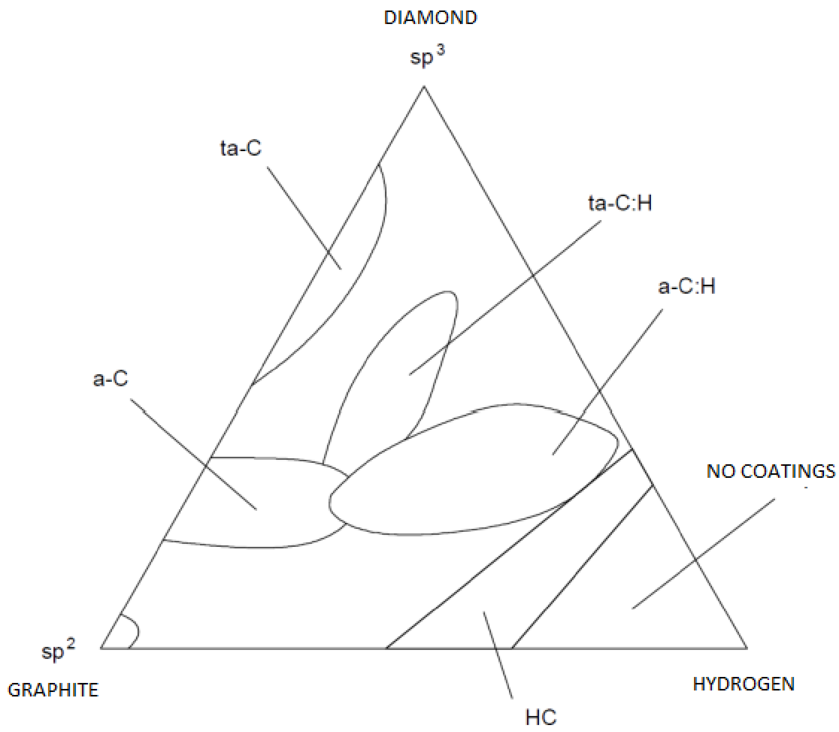



*Fig. 2. Types of DLC coatings based on a chemical structure*

The $sp^3$ phase is responsible for chemical neutrality, high hardness and wears resistance. The $sp^2$ phase gives the DLC coating low friction coefficient and goof electrical conductivity. Their ratio is one of the most important structural characteristics that shall be taken into consideration in process of creating a desired DLC coating.

## 3. Mechanism of wear in different DLC coatings

The roughness of a surface is an extremely important component for a DLC coating. When hard film, such as DLC is combined with hard base surface, the roughness of a base may be copied on the surface of the coating. Hard and rough surface generates higher and quicker wear. Then, the thickness determines what happens with the coating – if it is thick, only the coating is scratched. If the film is thin, both coating and base material are scratched, which is highly undesirable situation. If the base material is softer than film, the coating serves a protecting and wear-resistant role. However, if the surface of base is not hard enough to carry the load and friction, the coating may crack and loss its protective function. In consequences, the base material is deformed as well. To eliminate this problem, thicker coatings must be used for soft base material. All those dependencies are shown in Fig. 3.

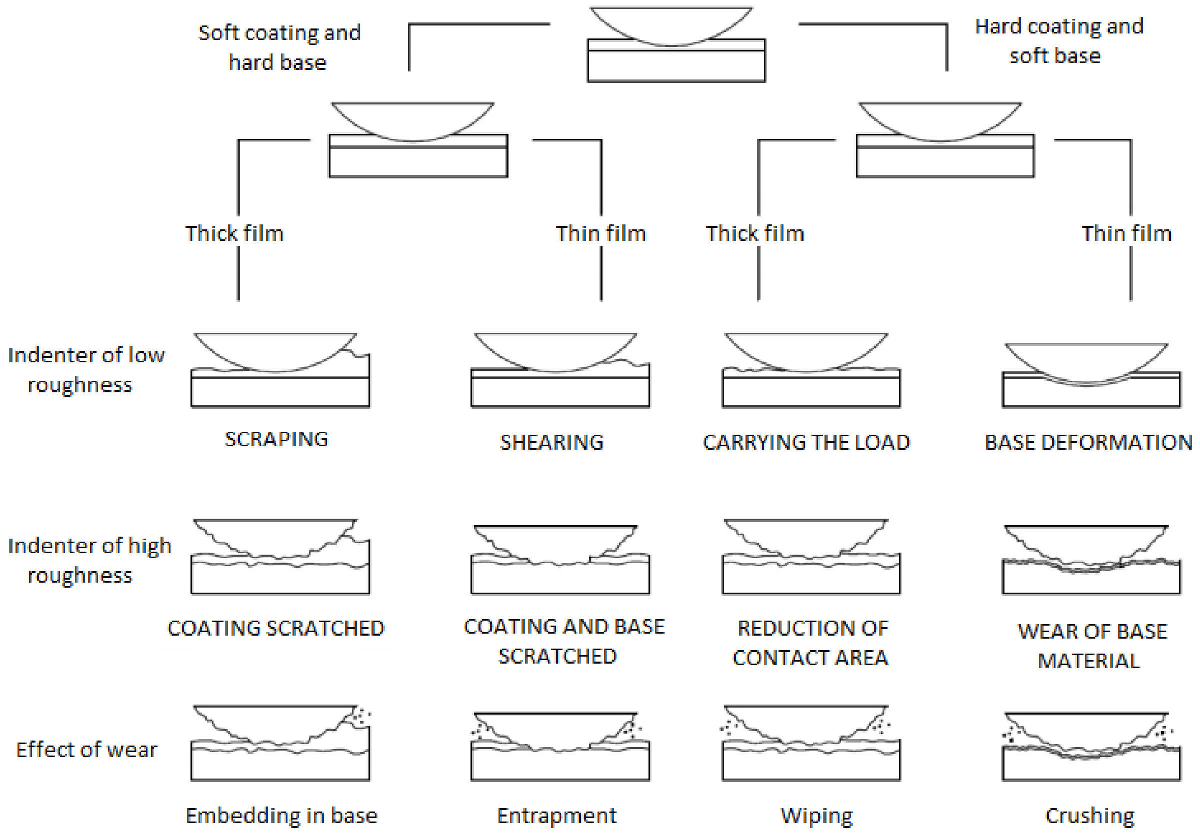


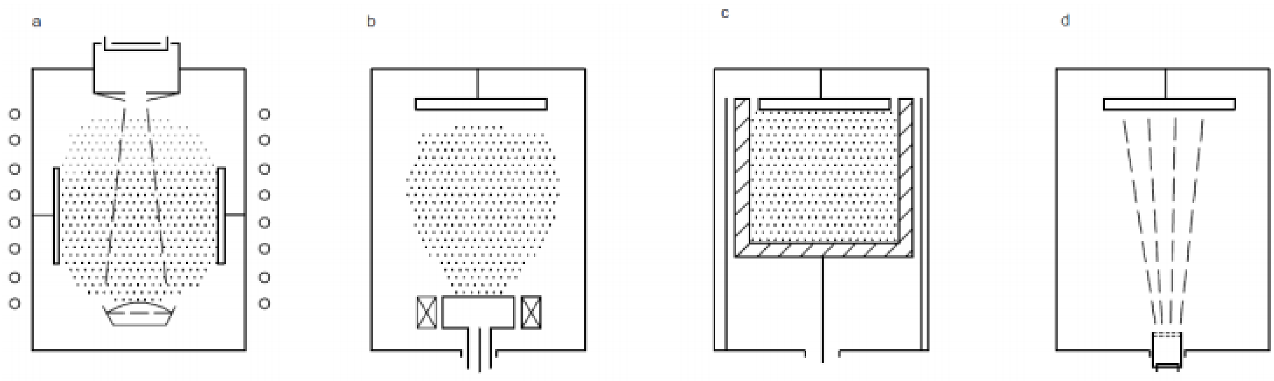

*Fig. 3. Mechanism of wear for different combination of base material and coating*

To increase the thickness and furthermore, the good adhesion to substrate, few methods may be used. To better describe the existing possibilities, Author decided to divide them into three main groups: changing the method of implementation the coating on the base, changing the chemical structure of a coating by adding metals or intermediate layers and improving the adhesion and wear resistance of a coating without changing its thickness. In this article, basic overview of all those possible methods is presented. This kind of knowledge will later be helpful in achieving Author's main goal – creating a DLC coating that is able to perform in extremely hostile environment of internal combustion engine and has an excellent friction coefficient.

## 4. Optimal method of implementation in terms of good adhesion

The PAPVD process (Plasma Assisted Physical Vapour Deposition) is one of the most effective technologies in coating metals in thin films. The main principle of PAPVD is plasma vapour deposition from gas phase with lowered pressure ($10\text{-}10^{-5}$ Pa), while the temperature oscillates between 150-5000°C. Vapour deposition allows coating the base material in a film of few micrometres thick. The connection is mainly adhesive or adhesive and diffusive. The vaporised material is almost entirely ionised and gives a plasma of high kinetic energy. Ions of metal react with a reactive gas and hit the base material with high energy and velocity. Resulting coating is considered thin, but its adhesive characteristics are excellent. In Fig. 4, different PVD methods are shown.

To explain why PAPVD methods of coating implementation shall be used for DLC films, the comparison between this method and CVD (Chemical Vapour Deposition) may be helpful. In CVD technology, the films must be put on toughened and prepared base. Without this, the resulting coating will not be hard enough. Therefore, thin and adhesively weak coatings are made using CVD. The PVD methods eliminate the need to prepare the base material so extensively, resulting in cleaner, smoother, harder and adhesively better film.




a - reactive vapourising activated by thermo-ion arch, b - vapourisation by an electric arch with an electromagnetic localization of kathode, c - direct deposition in kathode, d - straight deposition from ion clusters

*Fig. 4. Different PDV methods*

## 5. Addition of metals or interlayers

Monolayered and gradient DLC coating are most often a structures based solemnly on a-C or ta-C film, but can be modified with metals and non-metals. Studies show that adding metal to the structure results in increased sp$^2$ phase fraction and gives the coating a beneficial decrease of internal stress. In addition, by adding carbide-creating particles, such as Ti or Si, the coating may achieve better hardness due to formation of carbides. Metal incorporation also improves the electrical resistivity, dropping it significantly. By conclusion, an overall adhesion of a film is improved.

The idea of multilayering the DLC coatings is based on a desire to overcome some known problems with pure DLC characteristics, and also to achieve particular values of a coating. Various studies determined, that multilayering allows the film to have better adhesion to the base (with use of carbide-forming metals), higher mechanical load capacity (with use of a buffer layer), lower residual stress, better mechanical factors (such as thickness and resistance to cracking) and better tribological factors. Main possibilities of changing the chemical composition are shown in Fig. 5.

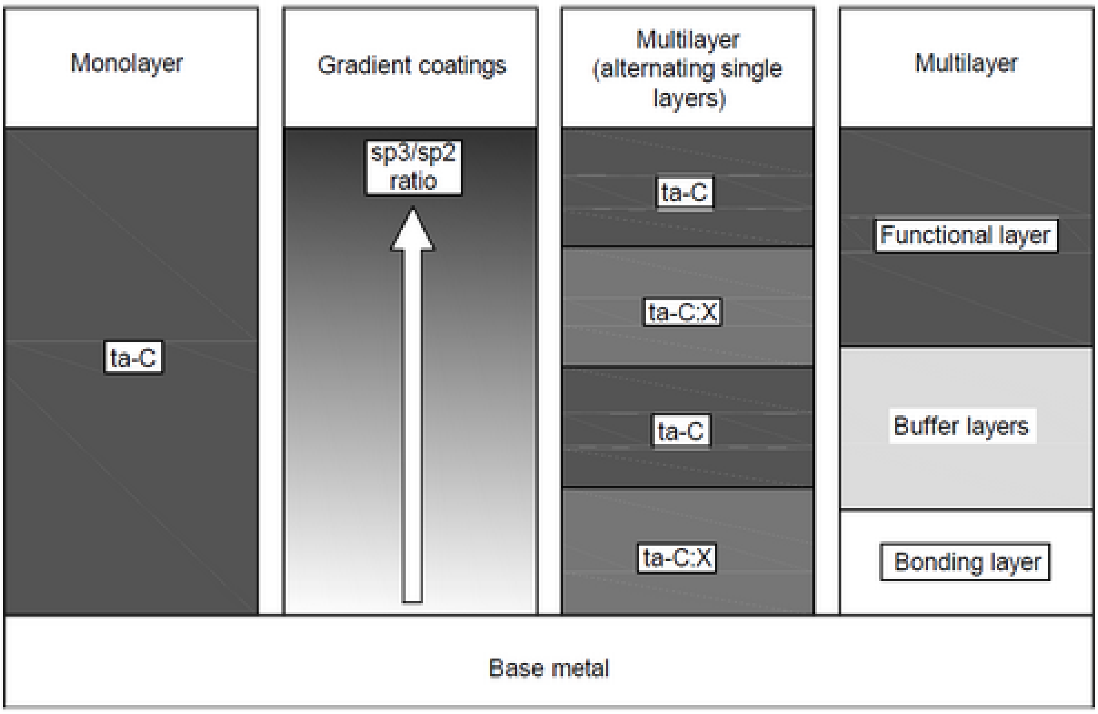



*Fig. 5. Types of coatings in terms of layers number*

## 6. Adhesion improving for very thin films

The DLC coating technology is not only used in medical and automotive industry. For example, in recent years, DLC is often used to protect the head or disc interfaces in magnetic storage devices. Thinner films prevent oxidation and create a possibility to increase the storage capability of such devices. It was observed than while thicker coatings provide slightly better resistance, thinner ones were also able to protect base surface against nanowear. The test were conducted for a contact pressure of approx. 11.5 GPa and the depth of indentation was similar for 2 nm coating as for 5 nm coating. The nanowear of coatings was mostly due to plastic deformation.

As explained above, one should not always strive to increase the thickness. In some cases lower thickness provide advantages that thicker films cannot. Also, increasing thickness unnecessarily to the situation results in higher cost of coating, higher material use and more difficult process of removing the film if it is necessary.

## 7. Conclusions

– Increasing the thickness of DLC coating has mostly positive influence on its mechanical, tribological and chemical characteristics. In addition, adhesion is dependent of the thickness,
– To create a coating that fits a particular need, many methods can be used. Those may be divided into technology changing, structure changing or utilization of thinner coating,
– PVD methods provide a good adhesion of the coating to base material, but their main disadvantage is high complexity and low availability of such technology,
– Change in structure by adding metals or interlayers can also increase thickness, which may result in very good adhesive characteristics,
– To obtain an optimal coating, both methods can be combined. In result, there is a possibility to control almost all the properties of a coating while decreasing the cost of its production at the same time.

## 8. Acknowledgement

This article is a result of research funded by the European Union under the Operational Programme Innovative Economy (POIG), as a result of project INNOTECH – III entitled “Implementation of the piston rings technology with the innovative coating anti-wear coating”. Contract No.: INNOTECH-K3 / IN3/41/228361/NCBR/14.

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