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HARD THIN COATINGS AND THEIR APPLICATIONS ON C60E NON-STANDARD GEARS

В статті наведені результати трибологічних лабораторних випробувань п’яти тонких твердих покриттів на трьох матеріалах, які використовуються при створенні зубчатих коліс. Оцінка проводилась по параметрам абразивної наноміцності, коефіцієнта тертя, зносостійкості, товщини покриття та його структури для покриття DLCI, нанесеного на зубчасту шестерню з опукло-увігнутим зачепленням, виготовлену з матеріалу C60E. Знос даних зубчастих коліс був протестований на стенді Ньюмана з використанням в якості змащування органічних мастил Biohyd MS46 та BioGear S150. Результати випробувань показали, що через особливі умови для зубчастих коліс, які спрягаються, неможливо розробити покриття для зубчатої передачі тільки на основі лабораторних випробувань – необхідно враховувати конкретні вимоги до нанесення покриття, типу та виду передачі а також матеріалу колеса.

Ключові слова: випробування на абразивну міцність, PVD, тверде покриття, зубчасте колесо з опукло-увігнутим зачепленням, стенд Ньюмана, C60E.

В статье представлены результаты трибологических лабораторных испытаний пяти выбранных тонких твердых покрытий на трех материалах, используемых при изготовлении зубчатых передач. Оценка проводилась по параметрам абразивной нанотвердости, коэффициента трения, износостойкости, толщины покрытия и его структуры для покрытия DLCI, нанесенного на зубчатую шестерню с выпукло-вогнутым зацеплением, изготовленным из материала C60E. Износ данных зубчатых колес был протестирован на стенде Ньюмана с использованием в качестве смазки органических масел Biohyd MS46 и BioGear S150. Результаты испытаний показали, что из-за особых условий для сопрягаемых зубчатых колес невозможно разработать покрытие для зубчатой передачи только на основе лабораторных испытаний – необходимо учитывать конкретные требования к нанесению покрытия, тип и вид передачи а также материал колеса.

Ключевые слова: испытание на абразивную прочность, PVD, твердое покрытие, зубчатое колесо с выпукло-вогнутым зацеплением, стенд Ньюмана, C60E.

The article presents the tribological results of laboratory applications five selected thin hard coating on the three materials used in the manufacture of gears. Based on their evaluation in terms of scratch test nanohardness, coefficient of friction, wear resistance, coating thickness and its structure was DLCI coating applied to the gear of the C-C gearing made of material C60E. Thus coated wheels lubricated with organic oils Biohyd MS46 and BioGear S150 were tested for scuffing to the Niemann´s stand. The test results showed that due to the specific conditions for mating gears is not possible to design a coating for gear based on laboratory tests only, but should be based on what the specific requirements for the gear to be applied coating, ie. what type and kind of gearing and on what material wheels.

Keywords: scratch test, PVD, hard coating, C-C gearing, Niemann´s stend, C60E.

1. Introduction. The gearing consists of power transmission, which are placed particularly high demands on durability and reliability. With increasing of its speed growth rate additional dynamic forces in gearing, which are make increase of vibration and noise and with increasing load also increases friction work and with it also increases the thermal load them. These facts are adding stress whitening, which carries an increased risk of damage to the gears [1–3]. These factors place increased demands on production quality and precision gears.

One possible way of increasing the surface properties of the gears and thus increase the loading capacity of minimizing the surface damage of the tooth side during the operation, which can be affected in several ways, e.g. changing material, changing the gearing geometry, heat treatment, chemical heat treatment or formed on the surface side of the tooth thin isotropic film.

Coating can be defined as a process that results in the creation of a thin coating on the isotropic working surfaces of parts to improve their surface properties. Practical use can be seen especially in the use of artificial thin layers (coatings). The development of thin-layer technology, mainly due to vacuum technology and capabilities that a precise and sensitive diagnostic methods needed to study the properties of these thin films [4].

From the point of view of physico-chemical processes taking place in the creation of coatings, coating processes can be generally categorized into three groups:

1 CVD (**C**hemical **V**apour **D**eposition),

2 PACVD (**P**lasma **A**sissted **CVD**),

3 PVD (**P**hysical **V**apour **D**eposition).

The required temperature at the application hard thin coatings shown in fig. 1. From the analysis of the size of operating temperatures shows that, for the application of coatings in gear transmissions can be used only by PVD, whose working temperature is below 500 °C. In this method is the low application temperature, there is no heat affected surface layers of parts and their deformation, and therefore this method is the most dynamic developing the coating methods.

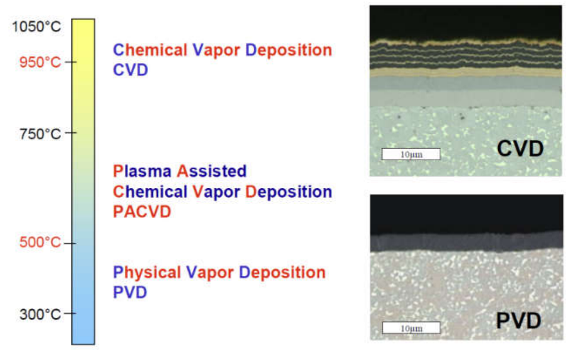

Fig. 1 – Working temperature coating technology CVD, PVD and PACVD

During deposition of PVD (Physical Vapour Deposition) layers are used by physical processes (heat, kinetic energy) to transform the deposited material from solid to gas. Thin layers deposited by PVD technology with a thickness of 0,0025 mm to a very high hardness, abrasion resistance and resistance to high temperatures.

PVD coatings have found wide application not only in the field of machining and forming, but now applied as well as in the production of gears, which creates conditions in the future also their wider use in gear power transmissions. Mostly coatings used in particular films based on amorphous carbon, known as DLC coatings. These layers are now used more types, the main difference being the method of deposition. However, there are a large number of different applications which may be a conventional or nanostructured PVD coatings. Both of the PVD coating can be in the form of monolayers and multilayers or gradient layers [5–7].

2. Evaluation of selected coatings on structural materials suitable for the manufacture of gear transmissions. In our workplace Institute of Transport Technology and Engineering Design Faculty of Mechanical Engineering Slovak University of Technology in Bratislava we are testing of selected PVD coatings in their application to non-standard convex-concave gearing (C-C gearing) with a low slip coefficient.

After detailed analysis of the fundamental tribological properties of thin PVD coatings have for their possible application in gearing we are selected five kinds of coatings: TiN, CrN, DLCI sandwich CR/CRN (plasma nitriding and PVD), duplex CRN (plasma nitriding and PVD), which were applied in laboratory samples for the selected construction materials suitable for the production of gears C60E, 16MnCr5, 41CrAlMo7. The results, as the volume loss of the coating on the substrate surface C60E are shown in fig. 2, the substrate 16MnCr5 in fig. 3 and the substrate 41CrAlMo7 in fig. 4 [8].

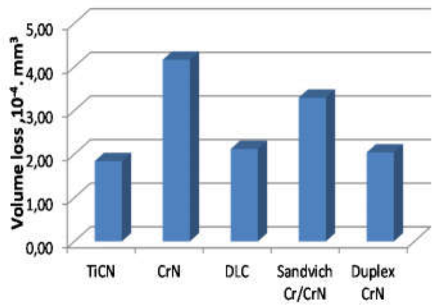

Fig. 2 – Volume loss of the surface selected coatings on the substrate C60E [8]

The course of the coefficient of friction on the selected materials is show in fig.5 for substrate C60E, in fig. 6, for the substrate 16MnCr5 and in fig. 7 for substrate 41CrAlMo7.

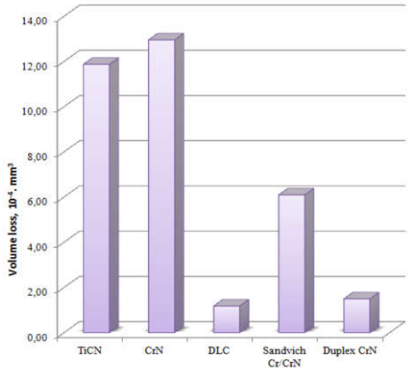

Fig. 3 – Volume loss of the surface selected coatings on the substrate 16MnCr5 [8]

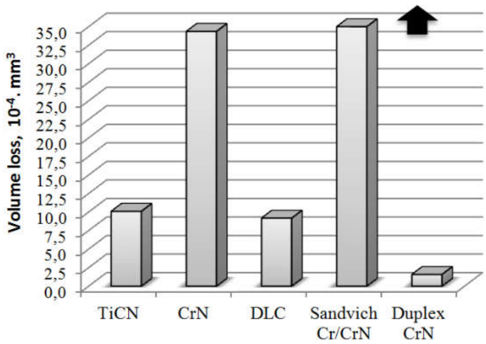

Fig. 4 – Volume loss of the surface selected coatings on the substrate 41CrAlMo7 [8]

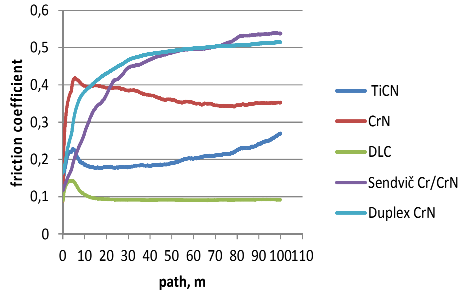

Fig. 5 – The course of the friction coefficient of selected coating on the substrate C60E

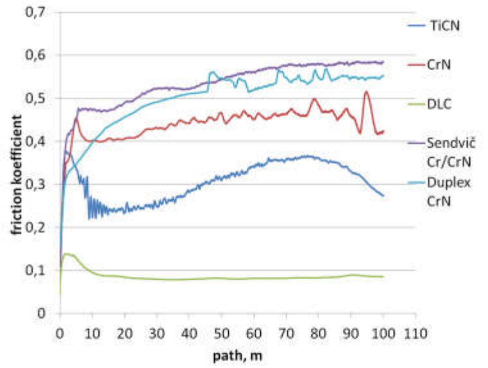

Fig. 6 – The course of the friction coefficient of selected coating on the substrate 16MnCr5

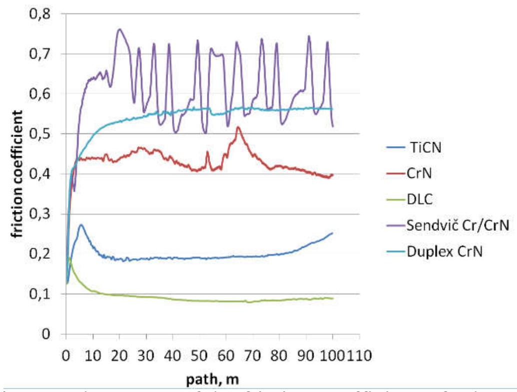

Fig. 7 – The course of the friction coefficient of selected coating on the substrate 41CrAlMo7

Based on the results obtained from the scratch test, analysis nanohardness, coefficient of friction, wear resistance, coating thickness and microstructure [8] can establish certain assessment test coatings on selected materials [9–11], which is listed in the table 1 for substrate C60E and substrate 16MnCr5 and in table 2 for substrate 41CrAlMo7.

Table 1 – Substrate C60E and substrate 16MnCr5 [8]

👍 very good 👎 weak ✋ good	C60E					16MnCr5)				
	TiCN	CrN	DLC II	Sandwich Cr/CrN	Duplex CrN	TiCN	CrN	DLC II	Sandvich Cr/CrN	Duplex CrN
Scratch test	👎	👎	✋	✋	👍	✋	👍	✋	👍	👍
Nanohardness	👍	👍	✋	👍	👍	👍	👍	✋	✋	👍
Friction coefficient	👍	✋	👍	✋	✋	👍	✋	👍	✋	✋
Wear resistance	👍	✋	👍	✋	👍	✋	✋	👍	✋	👍
Thickness	👍	✋	✋	👍	👍	✋	👍	✋	👍	👍
Microstructure	✋	✋	✋	👍	👍	✋	✋	✋	👍	👍

From table 1 it can be concluded that the substrate C60E for coating DLCII has not score low, but only very good and good, therefore his laboratory results include the substrate C60E among the best.

Table 2 – Substrate 41CrAlMo7

very good (thumbs up); weak (thumbs down); good (open hand)	41CrAlMo7				
	TiCN	CrN	DLC II	Sandvich Cr/CrN	Duplex CrN
Scratch test	weak	good	good	very good	very good
Nanohardness	very good	good	good	good	very good
Friction coefficient	very good	good	good	weak	good
Wear resistance	good	weak	very good	weak	very good
Thickness	good	good	good	very good	very good
Microstructure	good	good	good	very good	very good

Title DLC is currently used to refer to a metastable state of an amorphous carbon containing a significant proportion of sp 3 bonds. These layers have very good mechanical properties, such as great hardness, chemical stability and excellent tribological properties. DLC layers therefore have great possibilities of its application in industry.

In the automotive industry, the DLC coating is applied to the tool, not only for the production of the components, but also to reduce friction in the parts of the motor, wear and corrosion protection, the coating is most often the piston rings, valves, pistons, pump parts, camshafts and the like. Tribological laboratory analysis shows the possibility to use the DLC coatings in the transmission mechanisms.

Operating conditions in mesh involute gears in interaction with the ecological lubricant [11–13] is significantly different from the laboratory conditions (high load and pressure in contact, a big specific slips and high temperatures in contact), therefore, we applied the coating to the non-standard C-C gearing, in which the contact pressure smaller and smaller slips. Niemann´s tests for scuffing showed, that applications of the DLCII coating for real gears did not confirm the good laboratory results. Niemann´s test for scuffing showed there was a peeling applied DLCII coating first on the addendum and then on dedendum of teeth and gradually the entire surface of the side of the tooth.

These results show that the coating DLC II applied to the convex-concave teeth working with organic lubricants OMV BIOHYD MS46 a OMV BIOGEAR S150 is be not very suitable coating for gearing mesh, because after a load level 4 was the coating DLCII wash out from the teeth [14].

3. Conclusion. From the results it can be concluded that given the specific operating conditions of mesh gears (high contact pressure, high temperature at the point of contact, type of lubricating oil and a specific slip in the gearing) can be in designing a suitable coating for gear based on standard laboratory tests only indicatively. For the design a suitable coating for gearings need to be analyzed for what particular type of gearing is the coating used and also to which material should be coating is applied, as in compliance with other standard conditions such as roughness, accuracy and hardness side tooth. For the critical parameters applied coating on gear teeth is in particular the adhesion to the base material, the hardness and the friction coefficient and lubricant oil.

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