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Investigation of tribological properties of CarbonX coating deposited on 100Cr6 steel

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Abstract

The article deals with a reduction of friction coefficient of bearing steel 100Cr6. Reduction of friction was achieved by means of a CarbonX DLC coating. The coating exhibited excellent friction and mechanical properties. This coating was applied to samples made of 100Cr6 bearing steel. The friction results of the CarbonX coating were compared to the friction results of the 100Cr6 bearing steel. Reducing the friction of 100Cr6 bearing steel resulted in reduced wear and increase lifetime. The friction process of the samples will take place in an environment without lubrication. The aim of the article is to verify the behaviour of the DLC coating without the presence of lubricant in the friction node. The achieved results are to be interpreted in the conclusion of article.

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1. Introduction

Most of the degradation mechanisms are initiated and propagated by defects occurring on the surface of components. For this reason, the formation of various surface layers is important to increase the durability and operational safety of components. Coatings can be applied for various reasons, such as increasing wear resistance, corrosion resistance, forming a thermal barrier, etc. (Pastorek et al., 2016, Ulewicz and Mazur, 2013). It is anticipated that application of CarbonX coating to the surface of 100Cr6 bearing steel will increase the performance of the components. In this way, the degradation process of the wear is eliminated or delayed, and the friction of the component is reduced (Brezničan et al., 2013).

The CarbonX coating is produced by a PVD technology (a physical way of coating in a vacuum) (Holleck and Schier, 1995). In this process, small coating thickness is obtained by means of physical principles. Physical coating methods are carried out at relatively low temperatures in the range of 200 °C to 500 °C. This range of temperatures does not significantly affect the substrate of the material (Radek et al., 2018).

2. Experimental

The experimental part deals with tribological properties of heat-treated steel 100Cr6 with and without coating. Experiments were performed to determine and compare the coefficient of friction between the *quenched bearing steel - steel* and *quenched bearing steel - CarbonX coating* at different loads (4.9 N; 9.8 N and 14.7 N). The work describes the influence of temperature during the deposition of PVD coating on the mechanical properties of heat-treated bearing steel 100Cr6 (Radek et al., 2018).

The experimental material is a bearing steel 100Cr6 with the chemical composition shown in Table 1. The 100Cr6 steel is mainly used for production of bearing rings and bearing elements for rolling bearings. Due to the high requirements for wear and fatigue resistance, bearing steels are very complicated for production and heat treatment (Fabian et al., 2017, Liščík et al., 2010).

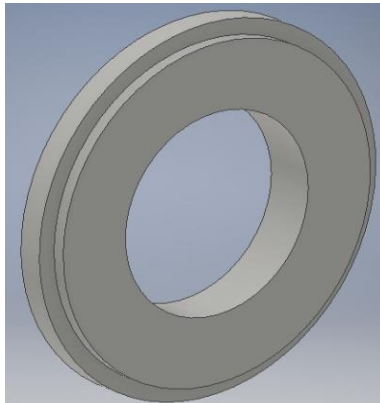
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Table 1. Chemical composition of 100Cr6 steel (wt. %)

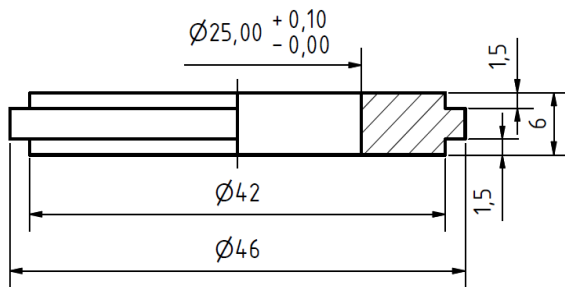
C	Si	Mn	P
1.05	0.35	0.45	0.0029
S	Cr	Ni	Cu
0.0033	1.55	0.182	0.170
Mo	Al	Co	Fe
0.072	0.030	0.01	balance

The shape and dimensions of the test sample are shown in Figure 1. The geometry and dimensions of the samples were selected according to the requirements of the T-01M test tribometer on which tribological tests were performed. The samples have the shape of a circular disk. The CarbonX coating was created by method of magnetron sputtering on

front side of the disc. The number of samples (discs) produced and subsequently tested was 4 (Liščić et al., 2010).



a) 3D model



b) dimensions

Fig. 1. Test sample (Vicen et al., 2019)

2.1. Tribology test

Tribological test is based on the Ball-on-Disc method which is a standard method for testing the tribological properties of materials. The main part of the rotary micro tribometer is a tribological pair consisting of a ball (fixed at the end of the holder) and a sample that has the shape of a circular disk. The ball is made of standard 100Cr6 bearing steel with a diameter of $d = 6$ mm. The hardness of ball is 750 HV. The ball motion was uniform and rotary speed was $v = 0.8$ m/s¹. The principle of the test is that load is affecting the ball and the sample with DLC coating at the same time. A normal load consisted of a set of weights which create the normal force F_N for load values $F_N = 4.9$ N, $F_N = 9.8$ N and $F_N = 14.7$ N. The friction force F_T was determined by tensometric measurement of the disk position. Duration of the test is $t = 5000$ s. Friction coefficient values were determined using the software and known values of F_T and F_N . The principle of the method is shown in Figure 2.

Tribological tests were performed on a special testing device T-01M for evaluation of friction and wear resistance of structural materials (Figure 3).

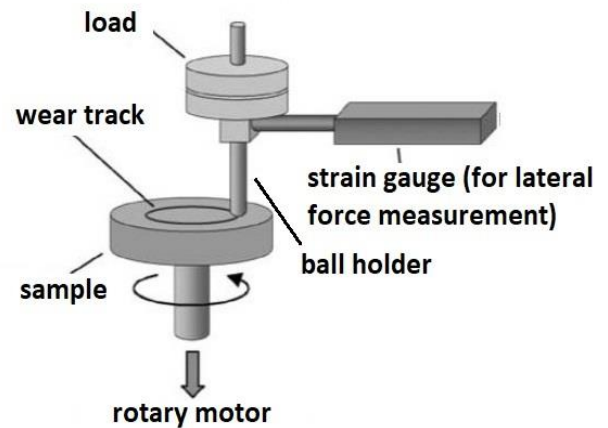


Fig. 2. Principle of Ball-on-Disc method



Fig. 3. Testing equipment T-01M (Radek et al., 2018)

2.2. Evaluation of hardness

The samples made from 100Cr6 bearing steel were heat treated by the conventional mode characteristic for this type of steel. Rockwell hardness was measured on all samples after heat treatment. The results are shown in Table 4. After the PVD coating process, hardness was measured on coated samples. The aim of the measurement was to verify the effect of the PVD coating temperature (240 °C) on hardness of material substrate. The results are shown in Table 5.

2.3. CarbonX coating

CarbonX is the new low-friction a-C:H based DLC coating. Due its hardness, this coating is the right choice for applications where high abrasive wear occurs and softer low-friction coatings reach their limits. The usage of CarbonX also efficiently reduces adhesions on components. The systematic build-up of layers combines multiple advantages of an a-C:H coating to ensure trouble-free tool performance, even under hard conditions (Drabik et al., 2018, Tsui and Garzon, 2017).

3. Results and discussion

The results of the experiment consist of evaluation of friction coefficient of material pairs, evaluation of hardness and metallographic evaluation of coating.

3.1. Evaluation of friction coefficient

The tribological system consists of two parts. The first member is a hardened bearing ball with a diameter of 6 mm and a hardness of 65 HRC and the second member is a test sample. Measured mean values of friction coefficients for individual tested loads are documented in Table 2 and Table 3. The results of the friction coefficients are shown in Figures 4, 5 and 6.

Table 2. Friction coefficient of quenched bearing steel - steel

Load [N]	Coefficient of friction [-]			Average coefficient of friction [-]
	1a	1b	2a	
4.9	0.907	0.809	0.850	0.855
9.8	0.958	0.651	0.794	0.801
14.7	0.754	0.746	0.725	0.742
Total friction coefficient				0.8

Table 3. Friction coefficient of quenched bearing steel - CarbonX

Load [N]	Coefficient of friction [-]			Average coefficient of friction [-]
	3a	3b	4a	
4.9	0.26	0.19	0.22	0.223
9.8	0.338	0.242	0.349	0.310
14.7	0.23	0.265	0.243	0.246
Total friction coefficient				0.26

Coated samples reached better friction values than uncoated samples. The friction coefficient results of the material pair *quenched bearing steel* – *CarbonX* coating are 3 times lower compared to *quenched bearing steel* – *steel*. Better results were obtained with all three loads tested. The CarbonX DLC coating deposited on 100Cr6 bearing steel substrate significantly improved friction properties. Friction results were obtained in the absence of lubricant which means that the coating exhibits good dry friction properties.

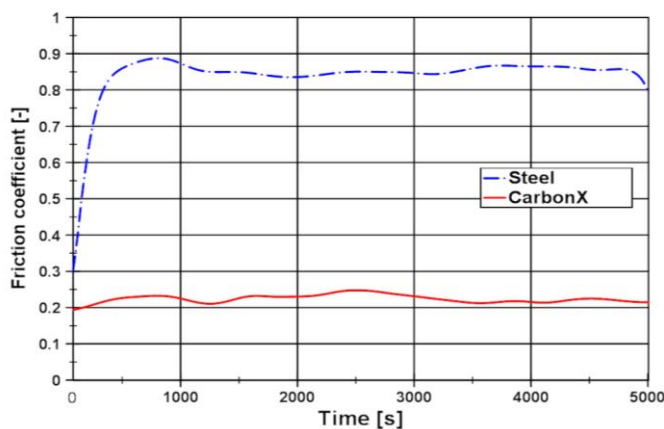


Fig. 4. Coefficient of friction, load $F_N = 4.9$ N

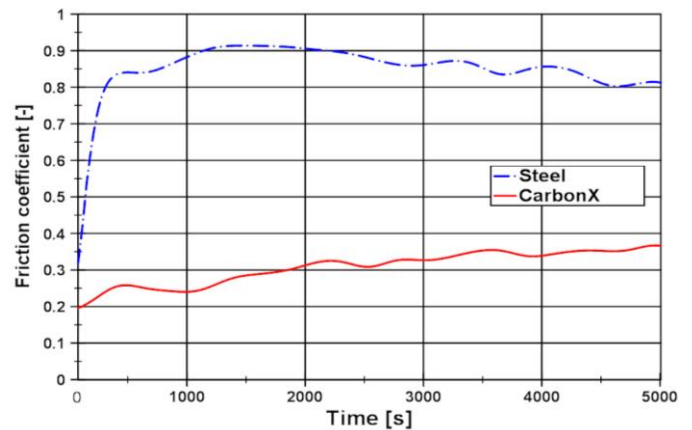


Fig. 5. Coefficient of friction, load $F_N = 9.8$ N

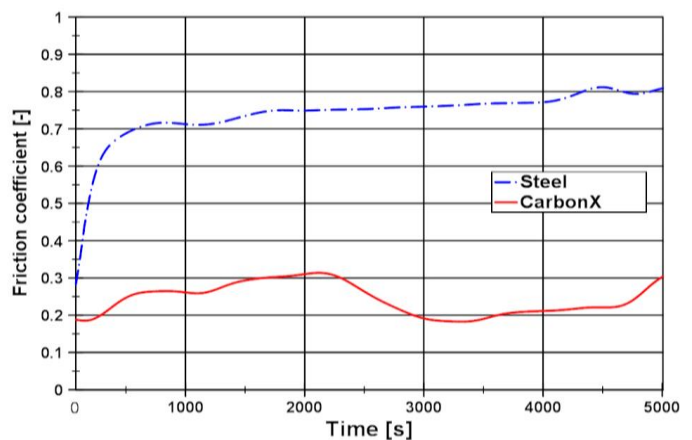


Fig. 6. Coefficient of friction, load $F_N = 14.7$ N

3.2. Evaluation of hardness

The hardness results of samples after the heat treatment are shown in Table 4. Average hardness of samples was 63 HRC. Hardness of samples decreased after PVD coating. The average hardness was 59 HRC. Samples were coated at temperature of 240 °C. This temperature caused a substrate hardness decrease of 4 HRC. Hardness of both materials fulfils the normative conditions for bearing steels. CarbonX coating shows significantly better friction properties than hardened 100Cr6 bearing steel with a hardness of 63 HRC.

Table 4. Hardness measurement after heat treatment

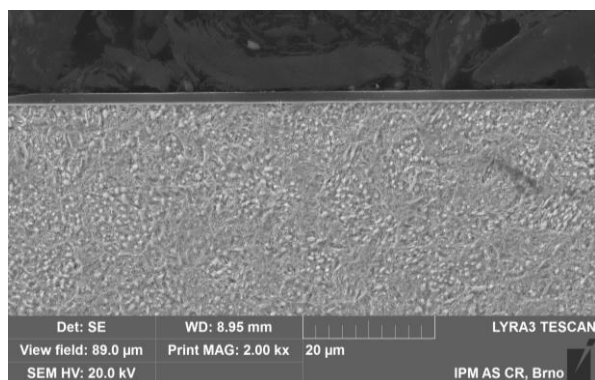
Nr. sample	Measurement number				Average hardness
	1	2	3	4	
1	63	63	63	63	63
2	63	63	63	62	63
3	63	62	63	63	63
4	62	63	63	63	63

Table 5. Hardness measurement after PVD coating process

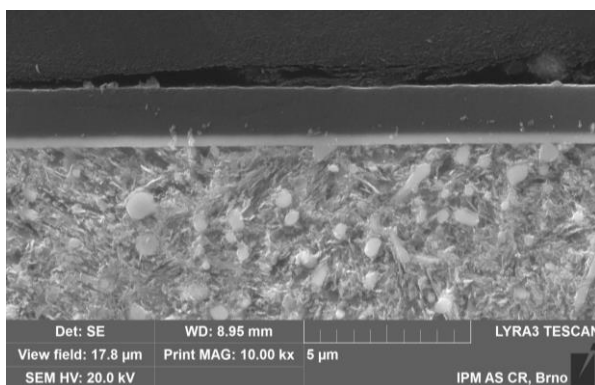
Nr. sample	Measurement number				Average hardness
	1	2	3	4	
1	59	59	58	59	59
2	58	59	59	59	59

3.3. Metallographic evaluation of coating

The CarbonX DLC coating is shown in Figure 7. The coating thickness is about 1.5 μm . This is a very thin coating that adheres to the surface of 100Cr6 bearing steel (Figure 7b). It is very important that the coating has good adhesion properties for proper function.



a) general view



b) detail

Fig. 7. CarbonX coating, etch. 0.5 % Nital, SEM

4. Summary and conclusion

The obtained results show that friction coefficient of 100Cr6 steel against steel has been successfully reduced. The result was achieved with a CarbonX coating applied to this steel. Friction coefficient value of 100Cr6 bearing steel against steel was on average $\mu = 0.8$ (-). The friction coefficient of this pair was reduced 3 times after the coating was created. Average friction coefficient value of the coating

against steel was $\mu = 0.25$ (-). These results were obtained in the absence of lubricant under dry friction conditions.

The coating temperature (240 °C) does not significantly affect substrate of the material. The substrate hardness was reduced by 4 HRC. The measured hardness of the 59 HRC substrate meets normative conditions for bearing steel.

CarbonX thin DLC coating formed on the surface of quenched 100Cr6 bearing steel significantly improves friction properties of this steel.

Acknowledgements

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100Cr6钢上的CarbonX涂层的摩擦学性能研究

關鍵詞

摩擦学
DLC涂层
100Cr6钢
摩擦

摘要

该文章致力于降低轴承钢100Cr6的摩擦系数。减少摩擦是通过CarbonX DLC涂层实现的。该涂层表现出优异的摩擦和机械性能。将该涂层应用于由100Cr6轴承钢制成的样品。将CarbonX涂层的摩擦结果与100Cr6轴承钢的摩擦结果进行了比较。降低100Cr6轴承钢的摩擦力可减少磨损并延长使用寿命。样品的摩擦过程将在没有润滑的环境中进行。本文的目的是验证DLC涂层在摩擦节点中不存在润滑剂的情况。本文的结论将对所取得的成果进行解释。