Research paper

DUPEX TREATED CrN COATING PROPERTIES EVALUATION ON DIFFERENT TYPES OF STRUCTURAL STEELS

Attila VANYA1,2, Mária HUDÁKOVÁ2, Miroslav BOŠANSKÝ3
1,3 Slovak Technical University, Faculty of Mechanical Engineering, Bratislava, Slovakia
2 Slovak Technical University, Faculty of Material sciences and Technology, Trnava, Slovakia

Received (27.03.2011); Revised (15.06.2011); Accepted (12.12.2011)

Abstract: A duplex CrN coating was deposited on three different structural steel substrates commonly used for gear production. Steels C60E, 16MnCr5 and steel 41CrAlMo7 were heat processed prior to the coating by standard heat treatment procedure. The CrN coating was deposited on the substrates by magnetron sputtering in pulse mode and by “cold regime”. The presented experiment is used to evaluate the properties of thin layers on the above mentioned substrates with the aim to select the most effective “coating-substrate” system and its application possibilities on the surface of convex-concave (C-C) gears. The microstructure of the base material and the layer growth were examined by light microscopy and with X-ray diffraction analysis. The microhardness of the coating was measured on Buehler INDENTAMET 1105.

Key words: duplex coating, magnetron sputtering, microhardness, C-C gearing.

1. INTRODUCTION

The present article deals with the evaluation of the application possibilities of a duplex CrN coating on structural steels used for gear production. The results of this research are directed to a coating creation suitable to increase the load carrying capacity and durability of convex-concave (C-C) gearing with reducing the adverse effects of thermal treatment on the gearing. The benefits of C-C gearing in comparison with the involute gearing (mesh of two convex tooth flanks) are thus results of the advantages of the mesh of convex teeth flanks with concave counter teeth flanks [1], where lower contact pressures are obtained (high contact carrying capacity) and better sliding relations occur in the gearing, which affects less wear, but can also manifest lower noisiness and subsequently could have final effect on greater durability and lifetime. Although there are some initial success using coatings technology in gear applications, much more research works still need to be carried out to understand the coatings, interfaces and substrate failure mechanism in gear application for surface engineering system design. Mao [2] performed experiments on gear wheels from high performance engineered steels duplex treated with TiN. Up to now were performed experiments on C-C gearings with TiN and MoS2 coating [3].

The tribological properties are limited with elastic and plastic deformations of the substrate, which can cause an early failure of hard surface layers. Hard particles removed from the surface layer could then cause further damage of the surface, by inducing an early abrasive wear of a part or the entire component. The attention has thus been recently turned on the duplex treatment of components and tools [4]. Duplex treatment means that surface treatment is combined with coating deposition to produce a surface with optimal tribological properties.

The surface treatment is applied prior to the coating deposition to enhance the surface performance, usually by enhancing the load support or load-bearing capacity provided to the coating to prevent it from cracking or debonding under load due to substrate surface deformation. The objective of using a duplex combination of a surface treatment and a coating is thus to provide a synergistic effect such that the resultant performance is better than either of the individual entities could provide alone [5]. Good load support for the coating is crucial for achieving long lifetime in many applications. Different kinds of surface responses can influence the limit of load support in a coated surface, as it is evident also from the results of our measurements. The most superior duplex layers are made as a combination of plasma nitriding and PVD coating. The nitried layer with increased hardness in comparison with base material provides better support for the PVD coating, how better mechanical and tribological properties can be achieved.

2. METHODOLOGY

The test samples were made from structural steels listed in Table 1, cut to segments from round staple bars with diameter D=90 mm. The samples were subsequently vacuum austenitized at 870°C, oil-quenched and tempered at 500°C.

Steel substrates prepared this way were then duplex treated with CrN coating under the same conditions. The surface treatment has been carried out in a Hauzer’s duplex coating system Flexicoat 850. Prior the CrN-coating, all the specimens were plasma nitrided. Plasma nitriding has been carried out at a temperature of 500 °C for 6 hours, in a low pressure atmosphere containing Ar and N2 in a ratio of 1:1. Before the deposition of ceramic film, the period with pure Cr deposition was inserted. The
CrN - coatings were deposited in a magnetron sputter pulse regime with a frequency of 40 kHz. Two targets, opposite positioned, were used. The targets were made from pure chromium (99.9%Cr). The cathode output power was 2.9 kW on each cathode. The processes were carried out in a low pressure atmosphere (0.15 mbar), containing the nitrogen and the argon, in a ratio of 1:4.5. The substrates were placed between the targets on rotating holders, with a rotation speed of 2 rpm. Just prior the deposition, the substrates were sputter cleaned in an argon low pressure atmosphere for 15 min. The substrate temperature was 250 °C as for the cleaning so for the deposition. Negative substrate bias of 200 V was used for the sputter cleaning and that of 100 V for the deposition. The total deposition time was 6 hours.

Table 1. Chemical composition of the steel samples

<table>
<thead>
<tr>
<th>Steel</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Cr</th>
<th>Al</th>
<th>Ni</th>
<th>Cu</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>41CrAlMo7 (15 340)</td>
<td>0.35-0.42</td>
<td>0.3-0.6</td>
<td>0.17-0.37</td>
<td>1.35-1.65</td>
<td>0.7-1.1</td>
<td>max 0.3</td>
<td>0.15-0.25</td>
<td>max 0.035</td>
<td></td>
</tr>
<tr>
<td>C60E (12 061)</td>
<td>0.57-0.65</td>
<td>0.5-0.8</td>
<td>0.15-0.4</td>
<td>max 0.25</td>
<td>max 0.3</td>
<td>max 0.04</td>
<td>max 0.035</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16MnCr5 (14 220)</td>
<td>0.14-0.19</td>
<td>1.1-1.4</td>
<td>0.17-0.37</td>
<td>0.8-1.1</td>
<td>max 0.3</td>
<td>max 0.04</td>
<td>max 0.035</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION

The coating thickness on each substrate was determined by Calotest and the results are shown in Table 2.

Table 2. Coating thickness determined by calotest

<table>
<thead>
<tr>
<th>Specimen</th>
<th>CrN-layer thickness (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>41CrAlMo7 (15 340)</td>
<td>3.86</td>
</tr>
<tr>
<td>C60E (12 061)</td>
<td>4</td>
</tr>
<tr>
<td>16MnCr5 (14 220)</td>
<td>3.48</td>
</tr>
</tbody>
</table>

The microstructure and the coatings growth were observed on the polished samples with final roughness 1 µm etched in 2% Nital.

Figure 1 represents C60E refined steel, where a sorbitic structure is evident, and on Figure 2 the same steel is showed with CrN coating on the substrate. On figure 3 the microstructure of 41CrAlMo7 steel after heat processing is shown, which is built by feritic-carbidic structure.

The microharness of the samples was measured on the coating surface by INDENTAMET with Vickers indenter. Results from the measurements are depicted on Figure 5, while the microhardness values at different loads are calculated as an average value from ten measurements.
The highest hardness of duplex CrN coating were recorded on substrate 41CrAlMo7 and the lowest on substrate C60E, which could be explained with the fact, that 41CrAlMo7 steel is suitable for nitridation and this ensures positive effects on the substrate-coating interface.

Coated amgels with area 10x10 mm were analyzed by „grazing incidence“ method by the means of X-raydiffractometer Philips PW1710 with secondary graphitic monochromator and Co anode. The results of the processed data are shown of Fig 6.

On each three samples, Cr2N phase with hexagonal structure P-31m (JCPDF 035-0803) was identified in the surface layers. From the comparison of the measured and tabulated intensities of this phase it can be concluded, that preferential orientation of crystallites was not observed. Excepting the Cr2N, any other nitrides were not observed. In the case of samples with substrate C60E and 16MnCr5 a plane reflexion 110 was detected from the steel substrate. The extension of Cr2N diffraction profiles refers about the presence of higher internal tensions in the layers. However, their values cannot be quantified. In general we can conclude that the differences between the observed layers are minimal. Similar results were documented also in previous experiments with comparable thicknesses of CrN coating on duplex treated steels [6].

4. CONCLUSION

From the experimental works carried out on duplex treated (plasma nitriding + CrN) structural steels the following could be concluded: The thickness of the coatings made at the same deposition parameters ranged between 3,48 and 4 µm. The microstructure of base materials after heat processing is built from feritic-carbidic compounds. The microhardness of the “coating-substrate” system was measured with Vickers indenter at different load levels, while the highest hardness was achieved with a duplex coating deposited on steel substrate generally aimed to nitridation. The phase composition of the deposited layers an X-ray diffraction analysis was performed, which showed the presence of only Cr2N phase in the coating layers. Further experiments will be performed on these samples to reveal the coating adhesion to the substrate, and a deeper microstructural analysis of coating’s microstructure on the base material by SEM. The results will be compared with other types of coatings on the same substrates.

REFERENCES


