MECHANICAL PROPERTIES OF THERMALLY SPRAYED COATINGS

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Abstract:

The present work is concerning with the mechanical properties determination of cermets thermally sprayed coatings, namely WC-Co and Cr$_3$C$_2$-NiCr coatings. The basic mechanical properties (e.g. superficial hardness, microhardness, elastic-plastic properties and indentation fracture toughness) were evaluated in dependence on process parameters, particularly on in-flight particle velocity and temperature. Particular attention was paid to the changes of coatings microstructure and mechanical properties, caused by heat influence. High temperature behavior of cermets coatings were evaluated in terms of hardness and microhardness.

1.1. Introduction

Thermal spray coatings are one of many methods for modification of part’s surface properties, taking advantage of possible combination of wide range of substrate materials and coatings. The technology is based on principle of melting and accelerating of fine particles (pure metals, alloys, cermets or ceramics) and their rapid solidification after impacting the substrate. Coatings with properties varying from very hard wear-resistant coatings to coatings with special physical properties on most of commonly used substrate materials can be created.

The main purpose of application of cermet coatings, such as WC-Co and Cr$_3$C$_2$-NiCr, is the increase of coated parts wear and oxidation resistance. The HP/HVOF sprayed cermet coatings are characterized by almost ideal combination of properties utilizing high hardness of carbides embedded in ductile metal matrix, which makes them the best choice in the case of abrasive and erosive wear.

The superior quality of cermets, in comparison with other types of coatings, is reached thanks to the technology of their deposition, High Pressure High Velocity Oxygen Fuel (HP/HVOF). HP/HVOF process represented by the systém TAFA JP-5000 has been proven in its ability to produce the best quality cermet coatings. The main advantage of this process is high powder kinetic energy of particle upon impact on a substrate and the suppression of powder particle overheating in the flame jet. It results in elimination of detrimental phase-chemical changes of sprayed material during particle flight dwell time and dense well-bonded, hard deposits [1,3,5,6].
The most important parameters affecting the quality of thermal sprayed coatings are particle temperature and velocity. These parameters can be altered over a significant range of conditions as a result of various chamber pressures and fuel/oxygen ratios at JP-5000.

In many applications (e.g. in power industry), the high temperature behavior of coatings is the main point of interest. Coatings behavior at high temperatures is usually evaluated according to amount of coatings surface oxidation [2,4]. Coatings oxidation resistance is determined by the ability of oxidation products to protect the surface against further oxidation. For example Cr$_3$C$_2$-NiCr creates on its surface a protective film of Cr$_2$O$_3$, that enables to use the coating up to high temperatures (cca 800°C [2]). On the contrary the oxidation products of WC-Co does not have any protective properties, so WC-Co starts to oxidize rapidly at about 400°C [1]. The temperature, at which coatings start to oxidize, is usually taken as a limit temperature for their applications. Exposition of coatings, which contain unstable amorphous and nanocrystalline phases thanks to rapid solidification, to the influence of high temperature caused beside oxidation also the change in coatings microstructure and related changes of coatings properties. Crystallization of amorphous phases, precipitation of carbides from their supersaturated solid solution in metal matrix and similar phenomenon can occur with increasing temperature [8,9]. The changes of coatings wear resistance with connections to microhardness changes can be also presumed [5,7].

2. Experimental

2.1. Coating Preparation

Coatings were sprayed onto grit blasted stainless steel substrates. The deposition parameters are summarized in table 1. The kerosene and oxygen flow rates were varied by reason of studying the influence of chambre pressure and equivalence ratio (representing the flame stechiometry) on coatings properties.

<table>
<thead>
<tr>
<th>Coating</th>
<th>WC-17%Co</th>
<th>Cr$_3$C$_2$-25%NiCr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powder</td>
<td>-type</td>
<td>agglomerated and sintered</td>
</tr>
<tr>
<td></td>
<td>-grain size</td>
<td>15 – 45 µm</td>
</tr>
<tr>
<td>Spraying system</td>
<td></td>
<td>JP-5000</td>
</tr>
<tr>
<td>Barrel Length</td>
<td></td>
<td>6“</td>
</tr>
<tr>
<td>Kerosene flow rate</td>
<td></td>
<td>variable</td>
</tr>
<tr>
<td>Oxygen flow rate</td>
<td></td>
<td>variable</td>
</tr>
<tr>
<td>Powder feed gas</td>
<td></td>
<td>Argon</td>
</tr>
<tr>
<td></td>
<td>-pressure*</td>
<td>60 psi</td>
</tr>
<tr>
<td></td>
<td>-flow rate</td>
<td>8 l/min</td>
</tr>
<tr>
<td></td>
<td>-feed screw</td>
<td>150 RPM</td>
</tr>
<tr>
<td>Spraying distance</td>
<td></td>
<td>360 mm</td>
</tr>
</tbody>
</table>

Tab.1.: Deposition parameters;
* 60 psi ~ 420 kPa

The denotation of coatings according the combustion chamber pressure (p) and equivalence ratio (Φ) for WC-Co and Cr$_3$C$_2$-NiCr is summarized in table 2a and table 2b, respectively.
Tab.2. a) denotation of WC-Co coatings and b) denotation of Cr$_3$C$_2$-NiCr coatings with respect to combustion chamber pressure $p$ [psi] and equivalence ratio $\Phi$

The deposition parameters, showing best results (marked in table 2 and 3), were used to create coatings that were further examined in terms of high temperature behavior. Selected coatings were annealed for 1 hour at 400, 500, 550, 600, 650, 700, and 800°C to study changes of microstructure, superficial hardness and microhardness of the coatings.

2.2. Testing Procedure

Superficial hardness HR15N and HR30N was measured according to ČSN ISO 1024003 using hardness tester Amsler - Wolpert Testor HT 2. At least five measurements were performed for each sample. Microhardness $HV_{0.3}$ was measured on the cross section of the coatings, using LECO DM 400A equipment. At least ten measurements were performed for each sample. Microhardness $HV_{0.1}$ were determined on the cross sections using an ultramicrohardness tester SHIMADZU DUH 202. For better understanding of elastic-plastic properties the load-depth dependence was recorded during indentation. A minimum of ten readings was taken for each coating. The indentation fracture toughness of WC-Co and Cr$_3$C$_2$-NiCr was measured using Vickers indentor at a load of 120N and 75N, respectively. At least seven indents were made for each coating. Lawn equation [12] was used to calculate the value of coatings indentation fracture toughness.

3. Results and discussion

The results of superficial hardness HR15N and Vickers microhardness HV0,3 for WC-Co and Cr$_3$C$_2$-NiCr coatings in dependence on combustion chamber pressure and equivalence ratio can be seen from the following figures.
Figure 1: Superficial hardness and microhardness for WC-Co and Cr$_3$C$_2$-NiCr coatings in dependence on combustion chamber pressure and equivalence ratio.

It is significant from the figures, that superficial hardness and microhardness increase with the flame temperature (equivalence ratio) and with the in-flight particle velocity (combustion chamber pressure) for both cermet systems [10,11].

The indentation fracture toughness results (fig.2) do not show such a significant dependence on the deposition parameters as in the case of microhardness.

Figure 2: Indentation fracture toughness of WC-Co and Cr$_3$C$_2$-NiCr coatings in dependence on the combustion chamber pressure and equivalence ratio.

With respect to the results of overall analyzes, including the microstructure evaluation, deposition efficiency evaluation etc., the optimal spraying parameters were chosen for further examination. Arrows in figure 1 and 2 mark the optimized coatings.

High temperature behavior of the optimized coatings was studied in terms of microstructure and mechanical properties.
In the case of WC-Co coatings the superficial hardness decreased rapidly above 650°C. This phenomenon is caused by oxidation of WC-Co coatings, starting above 670°C. The oxidation products of WC-Co do not have any protective properties against further oxidation and make the superficial hardness even immeasurable. These observations are in a good correlation with previous thermal-thermophysical measurements [12].

Fig. 3. Microhardness and superficial hardness of heat treated WC-Co coating

The WC-Co microhardness measurement are indicative of microstructure changes above 600°C, which can be explained as the amorphous phase crystallization and WC and W precipitation from the supersaturated solid solution in the matrix. The changes of microstructure are further confirmed by the changes of elastic-plastic properties of WC-Co coatings, that shows a distinct increase of indentation stiffness above 550°C (see fig.4). The shape of indentation curves represents the amount of elastic and plastic energy absorbed during indentation and to refers to H/E ratio of the measured coatings. The material stiffness can be also expressed by a ratio of an elastic energy (We) to the total amount of energy stored during indentation (Wg) (fig.5).

Fig. 4.: Load-depth curve of heat treated WC-Co coating

In the case of Cr3C2-NiCr the increase of the microhardness above 600°C is caused by the creation of Cr3C2 from the matrix. A decrease of microhardness at lower temperatures is probably caused by relieving plastic deformation of the matrix introduced during impacts of particles (fig.6).
The microhardness decrease of Cr$_3$C$_2$-NiCr coatings in the range of 550 – 600°C is, as in the case of WC-Co, followed by the change of the unloading indentation curve slope. The superficial hardness of Cr$_3$C$_2$-NiCr coating follows the same tendency as microhardness because the existence of a thin protective Cr$_2$O$_3$ layer at higher temperatures does not affect the number of superficial hardness.

Fig.6. Microhardness and superficial hardness of heat treated Cr$_3$C$_2$-NiCr coating

The change of unloading indentation slope is followed by an increase of coating stiffness. This phenomenon can be also connected with the relieving plastic deformation of the matrix (fig 7. and 8.).

Fig.7.: Load-depth curve of heat treated Cr$_3$C$_2$-NiCr coating

Fig.8: Elastic recovery of heat treated Cr$_3$C$_2$-NiCr coating

The microstructure changes can be seen from following micrographs. The as sprayed WC-Co coating shows denser microstructure compared to Cr$_3$C$_2$-NiCr. At higher temperatures, the porosity does not change significantly, but in the case of WC-Co a decrease of thickness was observed at 700°C and 800°C due to oxidation of coating surface.
WC-Co as sprayed

Cr$_3$C$_2$-NiCr as sprayed

WC-Co at 600°C

Cr$_3$C$_2$-NiCr at 600°C

WC-Co at 800°C

Cr$_3$C$_2$-NiCr at 800°C

Fig. 9.: Microstructure of WC-Co and Cr$_3$C$_2$-NiCr as sprayed coatings and coatings at elevated temperatures

4. Conclusions

The dependence of WC-Co and Cr$_3$C$_2$-NiCr coatings mechanical properties on deposition parameters, namely combustion chambre pressure and equivalence ratio was evaluated. Based on the results, the optimal deposition parameters were chosen for further examination.
The high temperature behavior of selected coatings were examined in terms of indentation tests. The changes of superficial hardness, microhardness and elastic-plastic behavior with temperature were determined. The changes of coatings microstructure were observed by means of light microscopy. It was found that at temperature above 600°C some changes of microstructure occur in the case of both selected coatings, which can cause the changes mechanical properties. These changes can be explained by a creation of carbides from supersaturated matrix and by relieving of matrix plastic deformation.

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References