Abstract:
The equilibrium between solid and liquid phases in sintered composite materials has been studied. It is shown that closed surfaces, which bound dispersed phases, influence the mechanical equilibrium between these phases. An expression is derived for a dihedral angle in composite materials, which includes values of surface tensions at the phase interfaces as well as parameters of a composite equilibrium structure (phase composition, particle contiguity and coefficients of a particle geometry).

Keywords: Coating; Mechanical properties; Plasticity characteristic.

1. Introduction

Besides microhardness that is generally used for the certification of coating properties, a complete set of mechanical parameters has to be determined for reliable predicting of their behaviour under loading during exploitation. These mechanical parameters include the plasticity characteristic $\delta_H$, yield stress $\sigma_y$, Young’s modulus, characteristic temperature of deformation $T^*$, fracture toughness $K_{IC}$, etc. [1-4].

All these parameters can be determined by the indentation technique. Evidence referring to effective application of the fracture toughness criterion $K_{IC}$ for control of the structure and stressed state of ceramic coatings and metallic surface layers of low ductility have been justified in literature [4-12]. Nonetheless, only a few attempts dealing with determination of the plasticity characteristic $\delta_H$ for coatings were made recently [7].

Using the data published in Part I of this study (see Tab. III) [13] values of the plasticity characteristic $\delta_H$ and elastic deformation over indentation $\varepsilon_e$, which were determined for coatings, and those published previously for single crystals and bulk materials [3], are compiled in Tab. I. It could be seen that discrepancies appear when the results attributed to coatings and those determined for single crystals and bulk materials are compared. For carbide coatings based on metals of group IV-A values of the $\delta_H$ characteristic are much lower and the values of parameter $\varepsilon_e$ are sufficiently greater than those determined for single crystals of the same phase composition. Higher values of Vickers hardness for coatings compared to those for single crystals cause this phenomenon.

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One could reasonably think that this discrepancy could be attributed at the most to strain hardening caused by the grain structure of coatings. However, a comparison of the data for NbC-coating and those published for a NbC single crystal indicates that the opposite relation between the values of Vickers hardness and parameters $\delta_H$ and $\varepsilon_e$ is true. The same situation could be demonstrated for coating and polycrystalline material made of titanium nitride, TiN (see Tab. I). If so, it was assumed that variation of Vickers hardness and, hence, the values of parameters $\delta_H$ and $\varepsilon_e$ is caused by the non-metal fluctuations since this phenomenon is typical for carbides and nitride compounds [14, 15], which have a wide range of homogeneity.

### Table I
Comparison of the data for the plasticity characteristic $\delta_H$ and elastic deformation $\varepsilon_e$ determined for coatings, single crystals and pieces of polycrystalline materials.

<table>
<thead>
<tr>
<th>Composition</th>
<th>Coating</th>
<th>Single crystal* or polycrystalline material** [3]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HV, GPa</td>
<td>$\varepsilon_e$, %</td>
</tr>
<tr>
<td>TiC</td>
<td>35.9</td>
<td>6.43</td>
</tr>
<tr>
<td>ZrC</td>
<td>29.7</td>
<td>6.64</td>
</tr>
<tr>
<td>NbC</td>
<td>21.0</td>
<td>2.81</td>
</tr>
<tr>
<td>TiN</td>
<td>18.7</td>
<td>2.86</td>
</tr>
<tr>
<td>Cr</td>
<td>9.6</td>
<td>1.85</td>
</tr>
</tbody>
</table>

Notes: The plasticity characteristic was calculated according to a modified model [3] using Eqs. (1), (3), (7), (8) presented in [13].

Thus, the chemical composition of the coating was assumed to be the dominating factor that defines Vickers hardness and, hence, the values of parameters $\delta_H$ and $\varepsilon_e$. A comparison of the data for chromium coating and those published for bulk metallic chromium confirmed this suggestion. Tab. I illustrates that higher values of Vickers hardness for coating of galvanic chromium result in smaller values of the $\delta_H$ characteristic and, so, larger values of parameter $\varepsilon_e$ compared to those determined previously for bulk metallic chromium. Allowing for application of the galvanising process, fluctuation of the elementary composition for Cr-coating can occur due to its contamination by foreign additives.

This paper aims to study sensitivity of the plasticity characteristic $\delta_H$ to the phase and elementary composition of coatings. Effective application of the $\delta_H$ characteristic to the development of coatings and design purposes will be clarified also.

### 2. Experimental

Phase compositions and structural parameters of coatings employed in the present study as well as conditions of coating applications were shown in Tabs. I, II presented in Part I of this study [13]. In addition, both TiC-coating and TiN-coating, which contained different amounts of interstitial elements, were performed to study the effect of the elementary composition on the plasticity characteristic $\delta_H$ of compounds with a wide range of homogeneity.

The elementary composition of coatings was determined by electron-probe microanalysis (EPMA) supplied with the ZAF correction method. The compositional depth profiles for TiN-coatings were measured by Auger-electron spectrum analysis (AES).

Specific features of the test method procedure used in indentation experiments with coatings were described previously [13]. The plasticity characteristic $\delta_H$ was determined using proper equations (1), (3), (7), (8) presented in [13] and suggested originally by a modified theoretical model [3].
Poisson’s ratio relevant to the coating material was adopted from a handbook [16] whereas Young’s modulus was both adopted from a handbook [16] and determined experimentally by the nanoindentation technique. The values of Young’s modulus and Poisson’s ratio applied for coatings were listed in Part I of the present study (see Tab. III) [13].

3. Results

3.1. Elementary composition of coatings

A typical elementary composition of coatings is shown in Tab. II. The results showed that coating compositions are believed to be different compared to those typical for similar bulk compounds [15]. Foreign metals because of element diffusion from the substrate or surrounding mixtures when the DSM technique was employed alloyed coatings. A small amount of iron was found in carbide coatings when they were performed on carbon steels (see samples 1-4 indicated in Tab. II). The essential content of foreign metals was recorded additionally in carbide layers when stepwise processing capable of forming several layers of different composition was used (see sample 6 indicated in Tab. II).

<table>
<thead>
<tr>
<th>Specimen number*</th>
<th>Coating composition**</th>
<th>Elementary content (wt.%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TiC</td>
<td>Ti – 79.9; Fe – 0.2; C - rest</td>
</tr>
<tr>
<td>2</td>
<td>ZrC</td>
<td>Zr – 86.6; Fe – 2.4; C - rest</td>
</tr>
<tr>
<td>3</td>
<td>VC</td>
<td>V – 77.8; Fe – 2.0; Cr – 2.8; C - rest</td>
</tr>
<tr>
<td>4</td>
<td>NbC</td>
<td>Nb – 87.2; Fe – 2.1; C - rest</td>
</tr>
<tr>
<td>5-1</td>
<td>Cr$_{23}$C$_6$</td>
<td>Cr – 63.0; Fe – 28.0; C - rest</td>
</tr>
<tr>
<td>5-2</td>
<td>Cr$_7$C$_3$</td>
<td>Cr – 76.2; Fe – 14.7; Ti -0.9; C - rest</td>
</tr>
<tr>
<td>6-1</td>
<td>TiC</td>
<td>Ti – 52.3; Fe – 10.8; Cr – 19.0; C - rest</td>
</tr>
<tr>
<td>6-2</td>
<td>δ-TiN</td>
<td>N – 40.0****; (C+O) – 5.3****; Ti - rest</td>
</tr>
<tr>
<td>8-1</td>
<td>FeB</td>
<td>Cr – 1.0; Mn – 1.0; Fe and B - rest</td>
</tr>
<tr>
<td>8-2</td>
<td>Fe$_2$B</td>
<td>Cr – 1.3; Mn – 1.2; Fe and B - rest</td>
</tr>
<tr>
<td>9-1</td>
<td>FeB***</td>
<td>-</td>
</tr>
<tr>
<td>9-2</td>
<td>Fe$_2$B</td>
<td>Cu – 1.8; Fe and B - rest</td>
</tr>
</tbody>
</table>

Notes: * - specimen numbers are similar to those indicated in Tabs. I, II, III presented in Part I of this study [13], ** - the composition is appointed in the direction from specimen surface to substrate; *** - the phase is presented in the form of individual crystals; **** - the content is defined by at. %.

A certain amount of carbon and oxygen ranging from 5 to 8 at.% was found in the composition of TiN-coatings. Probably, carbon and oxygen, which are typical foreign elements of the surrounding gas atmosphere, diffused in the condensate during its deposition. If so, TiN-coatings could be attributed actually to oxycarbonitride compounds.

It is notable that coatings made of titanium carbide and titanium nitride were referred to compounds of under- and over stoichiometric compositions ranging from TiC$_{0.92}$ to TiC$_{1.15}$ and TiN$_{0.82}$ to TiN$_{1.22}$, respectively. According to the modern standpoint [17] the increase of
interstitial element solubility could be caused by the nanocrystalline structure of these coatings.

Foreign metals were found in boride coatings performed on alloyed carbon steel (see sample 8 indicated in Tab. II) and those formed using the DSM technique with a powder mixture (see sample 9 indicated in Tab.II).

3.2. Influence of the elementary composition on the plasticity characteristic $\delta_H$ of coatings

Generally fluctuation of the material elementary composition causes variation of both of the hardness value and of Young’s modulus, resulting in the final value of plasticity characteristic $\delta_H$. The effect of alloying on Young’s modulus has a complicated character dependent on both the type of interatomic interaction and the strength of interatomic bonds. If so, the values of Young’s modulus for certain coatings were determined experimentally by the nanoindentation technique. The values of Young’s modulus, $E$, determined experimentally for some types of coatings (TiC, VC, Cr$_7$C$_3$) are listed in Tab. III presented in Part I of the present study [13].

![Fig. 1](image-url)

**Fig. 1** Summary of the data concerning the difference between the values of Young's modulus for coatings from a handbook, $E_{ab}$, and those determined experimentally, $E_{exp}$, vs. the content of alloying metals in the carbide compound. Coating compositions are marked by symbols and shown on the plot. Numbers by the symbols indicate the samples listed in Table II.

It can be seen that values of Young’s modulus determined experimentally and those found in a handbook for bulk compounds of the same phase composition [16] are quite similar. When coatings contained a small amount of foreign metals, Me < 4 at.%, (see Tab. III presented in Part I [13], samples 1, 1’, 3, 3’) the difference between experimental data and those published in literature [16] was believed to be as great as 5%, satisfying the scatter of data that is met typically in tests targeted to determination of Young’s modulus. However, the opposite is true for coatings alloyed strongly by foreign metals (see Tab. III presented in Part
generally, for ceramic coatings the value of Young's modulus increases almost proportionally as the content of foreign metals increases up to 22 at. %, as shown in Fig. 1.

It is considered usually that alloying of metals either by interstitial elements or substitution results in metal hardening, which causes a decrease in plasticity characteristics $\delta_H$ [2]. Compared to metallic materials, Vickers hardness of ceramic coatings is found to vary in a different manner when composition fluctuation occurs.

![Graph showing correlation of Vickers hardness, HV, and plasticity characteristic $\delta_H$ for coatings made of TiC and TiN vs. interstitial element content, C/Me, N/Me. Closed and open symbols indicate parameters such as HV and $\delta_H$, respectively.](image)

**Fig. 2** Correlation of Vickers hardness, $HV$, and the plasticity characteristic $\delta_H$ for coatings made of TiC and TiN vs. interstitial element content, C/Me, N/Me. Closed and open symbols indicate parameters such as $HV$ and $\delta_H$, respectively.

Fig. 2 shows a summary of the data referring to Vickers hardness, $HV$, and plasticity characteristic $\delta_H$ for coatings made of TiC$_{1+x}$ and TiN$_{1+x}$ plotted against the interstitial element content. It could be seen that Vickers hardness for the TiN$_{1+x}$-coating decreases and, so, its plasticity characteristic $\delta_H$ increases continuously as the nitrogen content increases in the region from N/Ti $\approx$ 0.8 to N/Ti $\approx$1.2.

Unlike the TiN$_{1+x}$-coating the results determined for the TiC$_{1+x}$-coating demonstrate that Vickers hardness, $HV$, increases and the plasticity characteristic $\delta_H$ decreases when the carbon content increases in the region from C/Ti $\approx$ 0.9 to C/Ti $\approx$ 1.0, as shown in Fig. 2. However, Vickers hardness decreases rapidly and, so, the plasticity characteristic $\delta_H$ increases in the same manner when the carbon content is higher than the point referring to the stoichiometric composition of titanium carbide, C/Me>1. As the carbon content further increases up to C/Ti $\geq$ 1.5, the values of Vickers hardness, $HV$, and the plasticity characteristic $\delta_H$ tend to be stabilized.

In addition, indications were obtained that alloying of a Fe$_2$B-layer with a small amount of foreign metals (see samples 8-2 and 9-2 marked in Tab. II) results in the actual change of parameters $HV$ and $\delta_H$ (see Tab. III presented in Part I of this study [13], samples 8-2, 9-2).
4. Discussion

4.1. Influence of the elementary composition on the plasticity characteristic $\delta_H$ for carbides and TiN-nitride

Using data published in literature for Vickers hardness for carbides based on metals of groups IV-A and Y-A and also for titanium nitride [14, 15], enabled correlation of values of the plasticity characteristic $\delta_H$ for the compounds given above vs. content of interstitial element, as shown in Fig. 3.

![Fig. 3 Correlation of the plasticity characteristic $\delta_H$ for bulk materials made of carbides and TiN-nitride, vs. interstitial element content, C/Me, N/Me. The values of hardness numbers used for calculations are adopted from data published in [14, 15].](image-url)

For carbides based on metals of group IV-A (TiC$_{1-x}$, ZrC$_{1-x}$, HfC$_{1-x}$) a strong decrease of the plasticity characteristic $\delta_H$ occurred with increasing carbon content up to C/Me $\approx$ 0.98 - 0.99. The same is true for TiN-nitride when the nitrogen content increases up to N/Me $\approx$ 0.97.

For carbides based on metals of group V-A (VC$_{1-x}$, NbC$_{1-x}$, TaC$_{1-x}$) different correlations of the plasticity characteristic $\delta_H$ vs. carbon content were revealed. Particularly, for VC$_{1-x}$ carbide the plasticity characteristic $\delta_H$ decreases slightly as the carbon content increases to the point indicated by C/Me $\approx$ 0.87 - 0.88. However, for carbides made of NbC$_{1-x}$ and TaC$_{1-x}$ the minimum value of the plasticity characteristic $\delta_H$ occurs when C/Me $\approx$ 0.82 - 0.85. Generally, values of the plasticity characteristic $\delta_H$ for carbides based on metals of group V-A (VC$_{1-x}$, NbC$_{1-x}$, TaC$_{1-x}$) are shown to be greater than those for carbides based on metals of group IV-A (TiC$_{1-x}$, ZrC$_{1-x}$, HfC$_{1-x}$). Compared to carbide compounds, TiN-nitride demonstrates the greatest value of the plasticity characteristic $\delta_H$ only if the nitrogen content corresponds to the relation N/Ti < 0.9.

It is interesting to discuss the results determined for coatings compared to those revealed for bulk compounds of the same phase composition. For TiC-coating the dependence of the plasticity characteristic $\delta_H$ on the carbon content is similar to that typical for bulk
titanium carbide (see Figs. 2 and 3). Furthermore, the value of the plasticity characteristic \( \delta_H \) for TiC-coating alloyed with a small amount of iron and the one obtained for an unalloyed bulk compound are found to be quite similar if only the carbon content in them was comparable, i.e. C/Ti \( \approx 0.9 \). The results indicate that Vickers hardness increases and, so, the plasticity characteristic \( \delta_H \) decreases as the carbon content further increases up to the stoichiometric composition (C/Ti \( \approx 1.0 \)), as shown in Fig.2. The decrease of Vickers hardness and, so, increase of the plasticity characteristic \( \delta_H \) that was recorded when the carbon content was just over the point referring to the stoichiometric composition of titanium carbide could be caused by precipitation of free carbon located at the grain boundaries when the TiC\(_{1+x}\) compound with a composition higher than the stoichiometric one is formed. The presence of free carbon located at the grain boundaries was assumed to cause the decrease of Vickers hardness for VC\(_{1-x}\) -carbide if even its composition does not exceed the stoichiometric one, C/V \( \approx 0.98 \) [15].

Attention should be drawn to the fact that the plasticity characteristic \( \delta_H \) for TiN\(_{1+x}\)-coatings increases continuously as the nitrogen content increases whilst the opposite is believed to be true for bulk titanium nitride, as shown in Figs. 2 and 3. In addition, for a stoichiometric composition the plasticity characteristic \( \delta_H \) for TiN\(_{1+x}\)-coating is found to be smaller than the value typical for bulk titanium nitride. Additive interstitial elements such as carbon and oxygen, which are contained in TiN\(_{1+x}\)-coating, can cause this phenomenon. It was found previously that the presence of carbon and oxygen in the composition of bulk nitrides results in microhardness changes[18].

Thus, the results determined in the present study indicate that the plasticity of coatings can be affected both by the content of interstitial elements and grain structure of the material.

The effect of alloying by foreign metals on coating plasticity is discussed also. The most interesting data was determined for a double layer coating performed by consecutive application of a TiC-layer and then Cr\(_7\)C\(_3\)-layer (see Tab. I presented in Part I of this study [13], sample 6). After application of the inner TiC-layer the amount of iron contained in the outer Cr\(_7\)C\(_3\)-layer decreased by about twice (see Tab. II, sample 6-1) compared to the value found for a Cr\(_7\)C\(_3\)-layer, which was formed by application of Cr\(_2\)C\(_6\)/Cr\(_7\)C\(_3\) coating (see Tab. II, sample 5-2). Furthermore, the Cr\(_7\)C\(_3\)-layer marked by number 6-1 is alloyed additionally by a small amount of titanium unlike to that formed in Cr\(_2\)C\(_6\)/Cr\(_7\)C\(_3\) coating and marked by number 5-2. Fluctuation of the elementary composition, which was found for the Cr\(_7\)C\(_3\)-layer marked by number 6-1, results in the increase both of Vickers hardness and of Young’s modulus, while its plasticity characteristic \( \delta_H \) remains quite similar to that determined for the Cr\(_7\)C\(_3\)-layer marked by number 5-2’ (see Tab. III presented in Part I of this study [13]). Since strong alloying of the inner TiC\(_{0.90}\) – layer of Cr\(_7\)C\(_3\)-TiC composite coating (see Tab. II, sample 6-2) results in a more pronounced decrease of Vickers hardness than Young’s modulus its plasticity characteristic \( \delta_H \) increases by twice compared to that found for an unalloyed TiC\(_{0.99}\)-layer (see Tab. III presented in Part I of this study [13], sample 1) whereas the carbon content for both layers was comparable.

Thus, the results determined in the present study indicate certainly that the plasticity characteristic \( \delta_H \) is highly sensitive to the elementary composition of coatings.

4.2. Application of the plasticity characteristic \( \delta_H \) for design purposes

The plasticity characteristic \( \delta_H \) is of increasing significance in a number of cases where effective optimisation of mechanical properties relevant to predicting coating behaviour under service conditions is important to research focused on both scientific and industrial applications. Indeed, the plasticity characteristic \( \delta_H \), fracture toughness, \( K_{ic} \), and
reasonable hardness should be taken into account to provide an adequate response of ceramic coatings to mechanical loading.

Several examples could be mentioned to demonstrate the role of the plasticity characteristic \( \delta_H \) in the subject matter. As the first example let us consider high performance of coatings under the fretting-fatigue condition. Coatings made of TiN, VC, Cr7C3 were found previously to be effective against fretting-fatigue [19]. Compared to other types of carbide and nitride coatings (e.g. Ti2N - TiN, TiC, ZrC) this phenomenon was attributed originally to high crack resistance of these coatings for which the value of criterion \( K_{ic} \) varied in the range from 2.5 to 2.7 MPa·m\(^{1/2}\). However, it seems to be strange that Vickers hardness determined for these coatings varied in a wide range of values (from 15 to 25 GPa) and in spite of the \( K_{ic} \) values were found to be comparable. Indeed, the relation between microhardness of the coating and that of the abrasive particles of wear debris, \( H_{HV} \), should be taken also into account when coating behaviour under fretting-fatigue is considered [20, 21]. Nonetheless, the results showed that different mechanical response of coatings to fretting-fatigue was found to be real in spite of the same relation \( H_{HV} \) typical for mechanical injuring of the material [19].

If so, an alternative explanation of this phenomenon could be given additionally using the results determined in the present study. The data listed in Tab. III included in Part I of this study indicate that values of the plasticity characteristic \( \delta_H \) for the effective coating vary between 0.55 and 0.65 whereas coatings made of other types of coatings (for example, TiC, ZrC, Ti2N-TiN), which could not be successfully applied, have values of \( \delta_H \ll 0.5 \).

Fig. 4 shows that worn surfaces of coatings made of effective coatings demonstrate only a few damages typical for pitting and fatigue furrows whilst the opposite is true for unsuccessful coatings for which fragmentation of fatigue furrows and a lot of pitting damages occurred since their plasticity characteristic and fracture toughness were inadequate \( \delta_H < 0.55 \) and \( K_{ic} < 2.2 \) MPa·m\(^{1/2}\). If so, coating plasticity adequate to resistance against fretting-fatigue occurs for actual values of the \( \delta_H \) characteristic ranging between 0.55 and 0.65. Coatings of this plasticity were used for effective application against fretting-fatigue conditions occurring in the application of fuel pump parts; blocks for air supply; hydraulic systems; screwed valves [21].
Attention should be drawn to the fact that high performance of coatings was ensured by methods and procedures for their application. For example, for TiN-coating that was effective against fretting-fatigue conditions certain nitrogen pressure and substrate temperature values were found experimentally using the method of Ion Bond Deposition [12]. Additionally, it was shown in [20, 21] that for application of a coating made of VC and Cr7C3, successful under fretting-fatigue conditions, use of the DSM procedure performed with molten salts [22] is preferable compared to the CVD technique [23-25].

Another example concerns application of carbide coatings for tool engineering. Effective application of double layer coating Cr7C3-TiC (see Tab. I presented in Part I of the present study [13], sample 6) for thread cutting and heading tools made of low-alloy steels (steel 9HS, HVG) was grounded by industrial tests [21]. This coating demonstrated a substantial increase of serviceability for the above tools, making them competitive with those made of high-speed steels. Application of only a single layer made of either TiC or Cr7C3 demonstrated a much smaller effect. Explanation of effective application of double layer Cr7C3-TiC coating was previously [21] by higher resistance to oxidation of the outer Cr7C3-layer compared to that typical for the inner TiC-layer. Nonetheless, alternative explanation of effective application of Cr7C3-TiC coating takes into account the plasticity characteristic $\delta_H$. The results show that both the Cr7C3-layer and TiC-layer (see Tab. III presented in Part I of the present study [13], sample 6) demonstrate reasonably high values of Vickers hardness (19.3 and 20.2 GPa) for almost the same values of the plasticity characteristic, $\delta_H = 0.47$ and $\delta_H = 0.45$, respectively. It is notable that the values of the $\delta_H$ characteristic for single layer TiC-coatings are smaller by twice in spite of an adequately high hardness value (see Tab. III presented in Part I of the present study [13], sample 1). Unfortunately, for a single Cr7C3-layer the hardness value is too small in spite of the an adequate value of the $\delta_H$ characteristic (see Tab. III presented in Part I of the present study [13], sample 6-2). Possibly, a combination of high hardness (HV >18 GPa) and a reasonable value of the plasticity characteristic ($\delta_H \approx 0.45$) that was typical for layers in the system Cr7C3-TiC could be assumed to be adequate properties for coatings used in cutting and heading conditions.

It was shown in literature [2] that the plasticity characteristic should be as high as $\delta_H > 0.90$ in order for bulk materials to demonstrate plasticity before fracture under standard tests for tension and bending. However, the results indicate that effective application of thin ceramic coatings can be achieved even under conditions when the plasticity characteristic $\delta_H$ has values smaller than the critical one, $\delta_H < 0.9$, when bulk materials are believed to be brittle. Possibly, this phenomenon occurs since the coating thickness is very small and, if so, elastic deformation has developed preferably under bending conditions, decreasing the risk of brittle fracture.

Allowing for the consideration above it can be concluded that the plasticity characteristic $\delta_H$ is actually quite informative for coating development and design purposes.

5. Conclusions

(1) Comparative analysis have shown that the difference between values of the plasticity characteristic $\delta_H$ for coatings and those published in literature for single crystals and bulk polycrystalline materials of the same phase composition could be associated both with fluctuation of the elementary composition and with the difference of grain structure.

(2) Using the data given in literature for Vickers hardness of carbides based on metals of groups IV-A and V-A and TiN-nitride, correlations of the plasticity characteristic $\delta_H$ vs. interstitial element content in the range of homogeneity of compounds were revealed.
Compared to carbide compounds TiN-nitride demonstrates the highest values of the plasticity characteristic $\delta H$ only if the nitrogen content corresponds to the relation $N/Ti < 0.9$.

(3) Contrary to bulk titanium nitride, the plasticity characteristic $\delta H$ for TiN$_{1+x}$ - coating was found to increase continuously as the nitrogen content increases in the region from $N/Ti \approx 0.80$ to $N/Ti \approx 1.22$. The opposite was found to be true for TiC$_{1-x}$ -coating when the carbon content increases up to $C/Ti \approx 1$. However, the plasticity characteristic $\delta H$ for TiC$_{1+x}$ - coating increases rapidly only if the carbon content is higher than the point referring to the stoichiometric composition and then it tends to stabilize when the carbon content further increases in the region from $C/Ti =1.05$ to $C/Ti=1.15$.

(4) Allowing for high sensitivity of the plasticity characteristic $\delta H$ both to phase and elementary compositions of coatings, the importance of the plasticity characteristic $\delta H$ for processing control and design purposes was founded on actual examples referring to engineering practice of effective coating applications. In particular, it was shown that ceramic coatings were effective against fretting-fatigue if actual values of the plasticity characteristic $\delta H$ lie in the range between 0.55 and 0.65 and fracture toughness is not less than $K_{IC}=2.2-2.7$ MPa$\cdot$m$^{1/2}$ while the value of Vickers hardness varied in the range from 15 to 25 GPa. Under cutting and heading conditions high hardness of about $HV \approx 20$ GPa combined with the plasticity characteristic of about $\delta H \geq 0.45$ could be assumed, possibly, as adequate properties for effective usage of ceramic coatings.

(5) It was assumed that for wear resistant ceramic coatings efforts aimed at the increase of the plasticity characteristic $\delta H$ are reasonable only if no substantial decrease of hardness occurs. In addition, the results indicate that effective application of thin ceramic coatings can be achieved even under conditions when the plasticity characteristic $\delta H$ has values less than critical, $\delta H < 0.9$, when bulk materials are believed to be brittle. Possibly, this phenomenon occurs since the coating thickness is very small and, if so, elastic deformation has developed preferably under bending conditions, decreasing the risk of brittle fracture.

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**References**


Резюме: С использованием адекватного подхода к определению характеристики пластичности δH показана ее высокая чувствительность к фазовому и химическому составу покрытий. С привлечением примеров эффективного использования покрытий в инженерной практике обоснована целесообразность применения характеристики пластичности для разработки и управления процессами нанесения покрытий стойких в условиях фреттинг-усталости, резания и высадки.

Ключевые слова: покрытие; механические свойства; характеристика пластичности.

Содержание: Примена одновраяиценого теориоосного принципа за одреяиваение характеристике пластичности δH омогулае ее одреяиваение високе осетиливость овог параметра према фазном и хемическом саставу превлаке. Задоволиваюа примена характеристике пластичности за контролу процесисрани и дизай заснована е на реали примерима из инженереске практике постоажных превлака под условима нагриза-замора, сечением и сабирана.

Ключные речи: превлаке; механика свойства; характеристика пластичности.