EVALUATION OF MECHANICAL AND TRIBOLOGICAL PROPERTIES OF HARDMETAL COATINGS DEPOSITED BY HVOF THERMAL SPRAYING METHOD

[1]Tomáš TARANDA, [2]Žaneta DLOUHÁ, [2]Jana NAĎOVÁ, [2]Šárka HOUDKOVÁ

[1]ZČU – University of West Bohemia, Pilsen, Czech Republic, EU, taranda@students.zcu.cz

[2]Research and Testing Institute Pilsen, Pilsen, Czech Republic, EU, houdkova@vzuplzen.cz

https://doi.org/10.37904/metal.2023.4722

Abstract

This article deals with the evaluation of the microstructure and tribological and mechanical properties of hardmetal coatings based on WC and CrC, which were applied to the base material S235JR by the HVOF thermal spraying technology. Experiments such as microhardness $HV_{0.3}$, superficial hardness HR15N, adhesion determination, abrasive wear and reciprocating sliding wear test were performed to compare the properties of the coatings and see how they differ depending on the selected additive material. Most of the tested coatings generally had high hardnesses, high wear resistance and reduced coefficient of friction, but were not significantly different. The only exception was the coating with the chemical composition 70(WC/Cr_3C_2)-21Ni9Cu, where the properties were significantly worse.

Keywords: Thermal spraying, hardmetals, WC, Cr_3C_2, HVOF, wear, properties

INTRODUCTION

Hardmetal coatings with high wear resistance have a wide range of applications and are highly sought after in various industries such as aviation, automotive, paper, and energy. Overall, it can be said that hardmetal coatings with high wear resistance are in demand where there is a need to increase component, tool, or equipment lifespan, reduce wear, and improve performance in manufacturing and industrial processes. One of the most common methods for applying these coatings is HVOF (High-Velocity Oxygen Fuel) spraying, which can provide coatings with high adhesion to the substrate, high hardness, high wear resistance, and low oxidation during the spraying process. Thanks to the high particle velocity and intense impact during HVOF spraying, it creates high-quality and dense coatings with minimal defects, which enhances their adhesion and durability.

A common type of wear-resistant material consists of hard carbides, particularly chromium carbides (Cr_3C_2) and tungsten carbides (WC), which are dispersed within a metallic matrix based on nickel (Ni), chromium (Cr), cobalt (Co), or a combination of these materials [1].

The evaluation of the mechanical properties of coatings included various tests that provide information about their hardness, strength, and other parameters. The hardness of the coating is important as it determines its resistance to abrasion. Strength is crucial for ensuring the adhesion of the coating and resistance to deformation. Tribological properties of the coatings are particularly important in applications where friction and wear occur. These properties were evaluated using various tribological tests, such as the ASTM G-65 abrasive wear resistance test and the ASTM G-133-22 linear reciprocating wear resistance test. The ASTM G-133-22 test provides information about the coefficient of friction between the coating and the opposite material in the form of an Al_2O_3 ball, while the ASTM G-65 wear test evaluates the volume loss of the material.

The evaluation of the mechanical and tribological properties of coatings enables the optimization of their composition, thickness, and spraying process parameters to achieve the desired properties.

1. MATERIALS

Materials based on WC (tungsten carbide) and Cr_3C_2 (chromium carbide) are often used for their excellent mechanical properties, such as high wear resistance and hardness, which are influenced by the size of the carbides in a tough matrix. Additionally, high hardness contributes to the enhanced durability of the coatings against wear. Coatings based on CrC are considered the best choice when combining high temperatures, mechanical stress, and a corrosive environment, as WC-based coatings cannot be used in applications where the operating temperature exceeds 400 °C due to the low oxidation resistance of tungsten carbide [2]. Combinations of these materials in different ratios (e.g. Amperit 543.074) or with additional additives can provide optimized coating properties for specific applications [3]. Table 1 provides an overview of the used materials and their chemical composition.

Table 1 Chemical composition of used materials

Materials designation	Chemical composition of used materials
Amperit 588.074	Cr_3C_2-25(Ni20Cr)
Amperit 543.074	42WC-42CrC-16Ni
Woka 3652	WC-10Co4Cr
Metco 5580A	70(WC/Cr_3C_2)-21Ni9Cu
Amperit 618.074	WC-FeCrAl 85-15

2. EXPERIMENTAL

The microstructure of the coating was observed on a cross-section of the sample after the spraying process. The main evaluated factors of microstructures were coating thickness, profile and structure of splats, quantity and locations of unmelted particles, pores, oxides, or other impurities. Furthermore, several mechanical and tribological tests were conducted. Specifically, these included superficial hardness HR15N, microhardness $HV_{0.3}$, adhesion test, abrasive wear resistance test, and linear reciprocating wear resistance test.

The superficial hardness according to Rockwell HR15N (ČSN EN IS 6508-1) was measured on the surface of a sample with a roughness of Ra 1.6 µm. The resulting values are the average of 7 measurements. Microhardness measurements according to Vickers (ČSN EN ISO 6507-1) were performed on a cross-section of the coating using a 300 g load and a diamond indenter in the shape of a square-based pyramid with a vertex angle of 136°. The resulting value is the average of 10 measurements. The adhesion test (ASTM C633-79) of the coating was conducted using HTK UltraBond 100 adhesive and a tensile test. Five measurements were performed for each material.

The ASTM G65 abrasive wear resistance test was divided into 5 cycles, with an abrasive path of 143.6 m per cycle and a total abrasive path of 718 m. White fused alumina with a grit size of F70 (210-250 µm) was used as the abrasive medium. Three measurements were taken for each set. The linear reciprocating wear resistance test was carried out using a linear oscillating motion of a 6.3 mm diameter corundum ball, applying a 25 N load on the sample for a duration of 1000 s over a 10 mm track length.

3. RESULTS AND DISCUSSION

3.1 Microstructure

All coatings after spraying show a high density and a minimum of pores and impurities. The thickness of all coatings ranges from 380 to 500 micrometers, which is an optimal thickness for better adhesion of the coating to the substrate material. At greater thicknesses, the adhesion of the coating would deteriorate [4]. The coatings of Amperit 588.074 (**Figure 1a**), Woka 3652 (**Figure 1c**), and Amperit 618.074 (**Figure 1e**) exhibited surface delamination, but it had no influence on the other conducted tests.

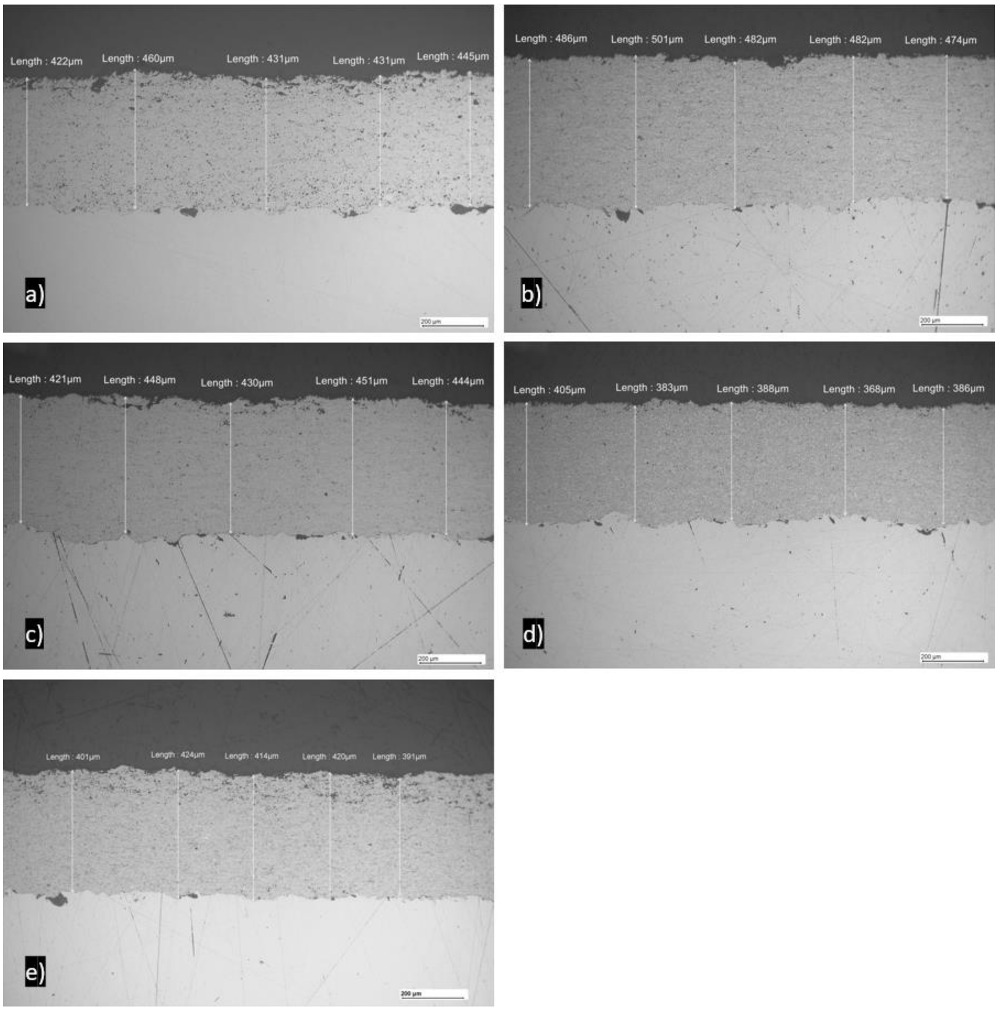

Figure 1 Microstructures of the tested coatings at 100x magnification: a) Amperit 588.074, b) Amperit 543.074, c) Woka 3652, d) Metco 5580A, e) Amperit 618.074

3.2 Mechanical properties

The superficial hardness HR15N includes the characterization of not only the coating material itself but also the structure of the spray coating. The resulting hardness value encompasses the influence of factors such as pores, splats, and the cohesive strength of the coating. It also depends on the orientation of the indenter impression with respect to the strongly anisotropic microstructure of the coatings. Particularly, tungsten carbides and chromium carbides increase the hardness of the coating. Coatings created using HVOF technology also have a high coating density, which is another reason for higher hardness values. In the case of Metco 5580A, the higher proportion of a soft matrix may also play a role [5]. The results of superficial hardness are presented in the graph shown in **Figure 2a**.

The measured microhardness values were very similar, and the difference in values was within the measurement scatter. Pradeep [6] found that higher WC content in WC-Co-Cr coatings leads to increased microhardness values. The microstructure of the coating, phase composition, and pore content also have a significant influence. From the graph in **Figure 2b**, it can be inferred that the quantity and composition of the material's matrix once again have an impact.

The adhesion measurements for all materials failed due to glue failure, and thus the exact adhesion values of these coatings cannot be determined. The achieved adhesion before the glue failure is recorded in **Table 2**.

Table 2 Overview of the results achieved of superficial hardness, microhardness and adhesion

	Superficial hardness HR15N	Microhardness HV0.3	Stressof speciment detachment [MPa]	Adhesion – type of failure
Amperit 588.074	87,9	1065	63,8	Glue failure
Amperit 543.074	89,8	1029	54	Glue failure
Woka 3652	88,3	1065	36,1	Glue failure
Metco 5580A	82,3	717	37,7	Glue failure
Amperit 618.074	89,3	988	39,6	Glue failure

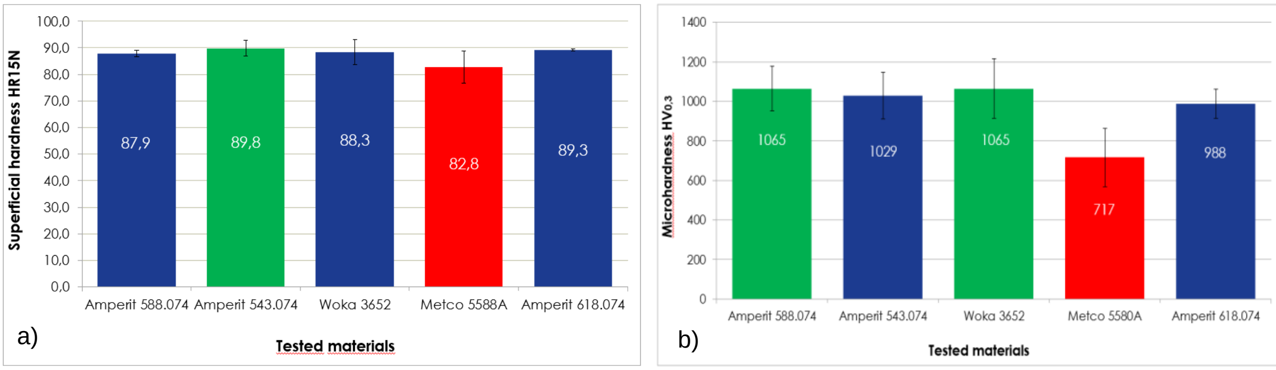

Figure 2 Graphs of basic mechanical properties: a) superficial hardness HR15N, b) microhardness HV0,3

3.3 Wear behaviour

The graph in **Figure 3** shows the comparison of cumulative volume loss for all coatings as a function of the traveled abrasive distance according to the abrasive wear resistance test. The Woka 3652 coating exhibits the highest durability, likely due to its higher content of WC and lower matrix proportion. Conversely, the Metco 5580A coating performs the worst in this type of wear. The possible cause could once again be attributed to the presence of a soft matrix, composed of Ni and Cu in this material, or a weak interface between the carbides and the matrix in which they are embedded [6]. The relationship can also be observed in the measured values of hardness and abrasive wear. Metco 5580A, which had the worst values of surface hardness and microhardness, also exhibited the poorest resistance to abrasive wear.

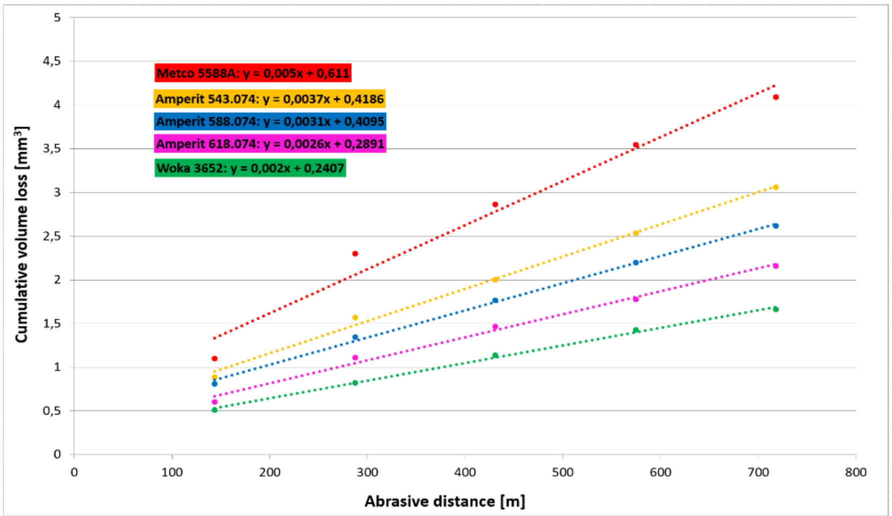

Figure 3 Cumulative volume loss of material depending on the traveled path after the abrasive wear resistance test.

The course of the coefficient of friction (COF) as a function of time for all tested materials is shown in the graph in **Figure 4**. COF is an important parameter for determining the material's resistance to frictional wear. A higher COF value indicates that the material is more susceptible to wear, while a lower value indicates greater resistance [7]. The COF profiles as a function of time for all measured coatings ranged between 0.4 and 0.45 once they reached a steady state. An exception is the Metco 5580A material, which exhibits a COF value around 0.25. One possible cause could be the presence of Cu in the matrix, which improves the frictional properties of the coating.

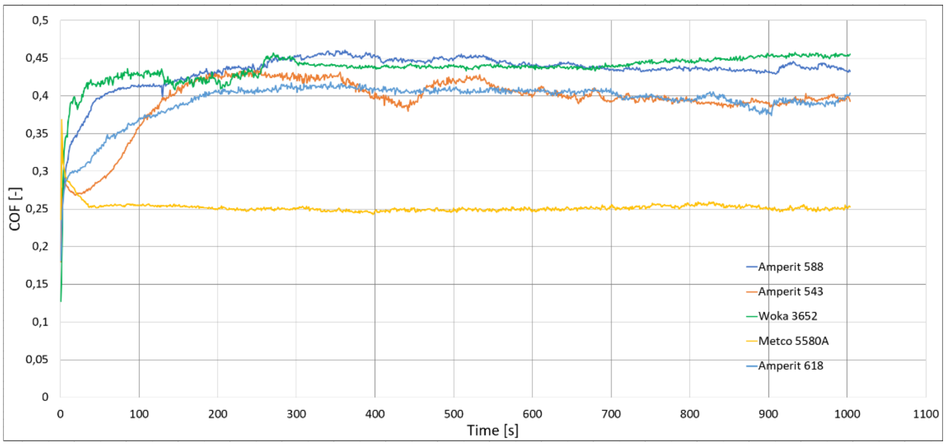

Figure 4 The course of the COF as a function of time for all tested materials

4. CONCLUSION

The aim of the experiment was to evaluate the microstructure, tribological, and mechanical properties of WC and CrC-based hardmetal coatings deposited on the S235JR substrate using the HVOF thermal spray technology. Most of the tested coatings exhibited generally high hardness, high wear resistance, and lower coefficient of friction, but they were not significantly different. An exception was the coating with a chemical composition of $70(WC/Cr_3C_2)$-21Ni9Cu (Metco 5580A), which showed lower surface hardness, microhardness, and abrasion resistance. Conversely, this coating had a significantly lower COF. Regarding the adhesion of the coatings, it is not possible to provide a specific value due to the failure of the adhesive. In conclusion, the coating Metco 5580A showed the worst results among the performed tests, while the coating Woka 3652 (WC-10Co4Cr) performed the best.

ACKNOWLEDGEMENTS

The paper has originated in the framework of the solution of project number SGS-2022-007.

REFERENCES

[1] OKSA, M., TURUNEN, E., SUHONEN, T., VARIS, T. and HANNULA, S.P. Optimization and Characterization of High Velocity Oxy-fuel Sprayed Coatings: Techniques, Materials and Applicatiobs. *Coatings*, 2011, vol. 1, no. 1, pp. 17-52.

[2] BERGER, L.-M. Application of hardmetals as thermal spray coatings. *International Journal of Refractory Metals and Hard Materials*. 2015, vol. 49, no. 1, pp. 350-364.

[3] BERGER, L.-M., SAARO, S., NAUMANN, T., KAŠPAROVÁ, M., ZAHÁLKA, F. Influence of feedstock powder characteristics and spray processes on microstructure and properties of WC–$(W,Cr)_2C$–Ni hardmetal coatings. *Surface and Coatings Technology.* 2010, vol. 205, no. 4, pp. 1080-1087.

[4] ENŽL, R. *Vysokorychlostní nástřik povlaků na bázi karbidu wolframu*. Plzeň, 2001. Dissertation. University of West Bohemia, Faculty of mechanical engineering.

[5] HOUDKOVÁ, Š., ZAHÁLKA, F., KAŠPAROVÁ, M., BERGER, L.-M. Comparative study of thermally sprayed coatings under different types of wear conditions for hard chromium replacement. *Tribology Letters*. 2011. vol. 43, no. 2, pp. 139-154.

[6] PRADEEP, D.G., VENKATESH, C.V., NITHIN, H.S. Review on tribological and mechanical behaviour in HVOF thermal-sprayed composite coatings. *Journal of Bio- and Tribo-Corrosion*. 2022, vol. 8, no. 30. Available from: https://doi.org/10.1007/s40735-022-00631-x

[7] MATIKAINEN, V., BOLELLI, G., KOIVULUOTOM H., LUSVARGHI, L, VUORISTO, P. Sliding wear behaviour of thermally sprayed Cr_3C_2-based coatings. *Wear*. 2017, vol. 388–389, pp. 57-71.