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The Effect of Detonation Spraying Mode on the Structure and Tribological Properties of WC–Co Coatings

The article presents the results of research into the structure and tribological testing of WC-Co detonation coatings with a barrel filling volume of 64 % and 74 %. X-ray diffraction analysis of the WC-Co coating revealed that undesirable Co and W_2C peaks disappear after detonation spraying. Morphological analysis showed that with 64 % and 74 % detonation barrel filling, the coatings had a dense structure with a thickness of 136 μm and 161 μm, respectively. EDS mapping showed a uniform distribution of elements. Tribological tests of the coating revealed that the friction coefficient of the samples ranged from 0.48 to 0.53 for 74 % and 0.55–0.57 for 64 %. Based on the results obtained, the optimal technological regime for obtaining wear-resistant WC-Co coatings by detonation spraying was established.

Keywords: detonation spraying, WC-Co coatings, tribology, coatings, microstructure.

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Introduction

Nowadays WC–Co based coatings are widely used to improve wear resistance, as well as corrosion and erosion resistance of engineering components, including valves, drill bits and downhole tool components used in the mining, oil and gas industries [1]. Due to their excellent wear resistance and mechanical stability, WC–Co coatings are commonly used for steel rolls, zinc bath rolls, corrugated rolls, pump housings, impeller shafts, compressor stators, and aircraft flap guides. Additionally, these coatings find application in cams and expansion joints operating under severe service conditions [2].

It has been established that the wear resistance of WC–Co coatings is significantly affected by various factors, such as the morphology, chemical and phase composition of the initial powder, the size and distribution of WC particles, and spraying parameters [3-4]. During thermal spraying of WC–Co, undesirable phenomena associated with the decomposition of carbide phases can occur. As a result, the content of the solid WC phase decreases, and decomposition products such as W_2C, metallic W, and amorphous or nanocrystalline Co–WC phases are formed instead. Therefore, to obtain hard alloys with high mechanical properties, it is necessary to minimize the decomposition of the WC phase.

Despite the widespread use of WC–Co coatings, numerous studies have shown that thermal spraying results in decarburization of WC particles. As noted by Ahmed et al. in their review, high temperatures and prolonged exposure of particles to the flame zone lead to the formation of W_2C, metallic W, and η-phases (M_6C and $M_{12}C$). This complicates the coating microstructure and reduces its mechanical properties [5].

Detonation spraying represents a very promising direction in the field of thermal spray technology, offering a viable solution for the production of high-quality wear-resistant coatings. Research by Du et al. showed that even at high oxygen-fuel ratios, the degree of WC decarburization remains low, allowing for the production of coatings with high density and strength [6]. This contrasts with plasma spraying methods, where WC decomposition is significantly more pronounced.

Yuan et al. showed that the introduction of submicron WC particles into the spray boundaries promotes the formation of a stronger interlayer structure, significantly increasing the wear resistance of HVOF coatings. WC–Co [7]. However, this type of spraying can lead to partial decomposition of the WC carbide phase, resulting in the formation of undesirable phases such as W_2C and metallic W.

The aim of this article is to study the influence of detonation spraying modes on the structure and phase composition of WC–Co coatings.

Materials and methods of research

WC–Co based coatings, low-alloy structural steel of grade 20 was selected as the substrate material. Samples were manufactured with dimensions of 50×50×7 mm. Before coating application, the substrate surfaces were ground on all six sides using MIRKA 1000-grit sandpaper to ensure a uniform and smooth surface. The samples were then sandblasted to improve the adhesion of the applied coating. After sandblasting, the samples were washed in an ultrasonic bath filled with 90 % alcohol to remove sand particles from the sprayed surface. The nominal particle size of the WC–Co powder ranged from 30 to 45 μm. The coatings were applied using a CCDS 2000 detonation complex (Russia). WC–Co coatings were obtained by filling the cylinder with explosive gas to 64 % and 74 %, respectively. The distance between the barrel of the detonation gun and the sample was 150 mm, and the number of shots reached up to 50 times per sample.

A SEM 3200 scanning electron microscope (China) equipped with an energy-dispersive spectrometer was used to study the microstructure of the coating cross-section. X-ray diffraction (XRD) analysis was performed using an X'PertPRO diffractometer with Cu-Kα radiation (λ=1.54 Å) at 40 kV and 30 mA to identify phases in the coatings and WC–Co powder. Diffraction patterns were collected over a 2θ range from 20° to 90° with a step size of 0.02° and a counting time of 0.5 seconds per step. The data were analyzed using HighScore software.

To study the tribological properties of WC–Co coatings produced by detonation spraying, a TRB3 tribometer was used in various tribology modes. All coatings were tested in the following modes: distance 100 m, speed 5 cm/s and 10 cm/s, trace radius 3 mm, and load 10 N and 15 N.

The volumetric wear of the samples was determined by Formula (1) as follows [8]:

$$W_v = \frac{V}{F_n \cdot s}\left[\frac{mm^3}{N \cdot m}\right], \quad (1)$$

where V — volume of wear material [mm^3]; F_n — normal force applied to the sample [N]; s — friction path [m].

Results and discussion

X-ray diffraction analysis was used to study the phase composition of the powder and coatings. Figure 1 presents the results of X-ray diffraction analysis of the detonation coatings and powder. The diffraction patterns identified the main peaks corresponding to the WC phase in both the original powder and the sprayed coatings. The powder also contains weak reflections belonging to metallic cobalt, indicating the presence of a binder phase. After detonation spraying, the Co peaks virtually disappear, indicating a redistribution of the binder cobalt or its partial dissolution in the carbide matrix during high-temperature exposure.

Compared to the original powder, the WC peaks in the coatings are somewhat broadened and less intense, which is due to a decrease in the average crystallite size and an increase in structural imperfections due to the rapid cooling of the molten particles. The absence of W_2C and metallic W phases indicates that no thermal decomposition of the WC occurred under the selected conditions, and therefore, the spraying process occurred under optimal conditions in terms of temperature and particle residence time in the plasma.

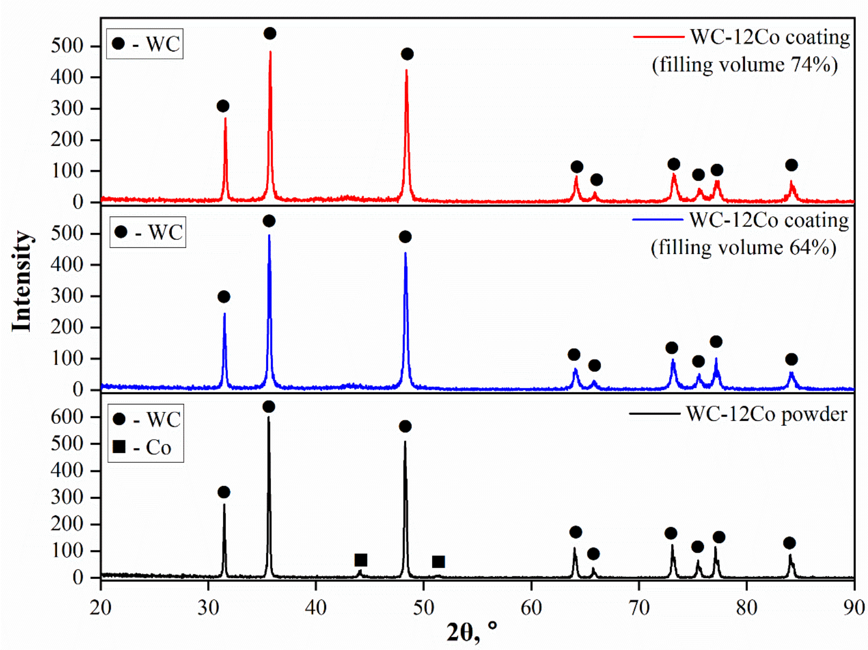


Figure 1. Diffraction pattern of detonation coatings and WC–Co powder

A comparison of coatings obtained with different barrel filling volumes (64 % and 74 %) shows that with increasing filling volume; the intensity and clarity of the WC peaks decrease slightly. This indicates an increase in thermal load, leading to partial recrystallization and the formation of internal stresses in the coating. With a smaller filling volume (64 %), the structure is closer to the original, with more pronounced WC peaks, confirming the preservation of the phase composition and minimization of thermal stress.

Figure 2 shows a cross-section of the WC-Co coating at a filling volume of the barrel of the CCDS 2000 detonation complex.

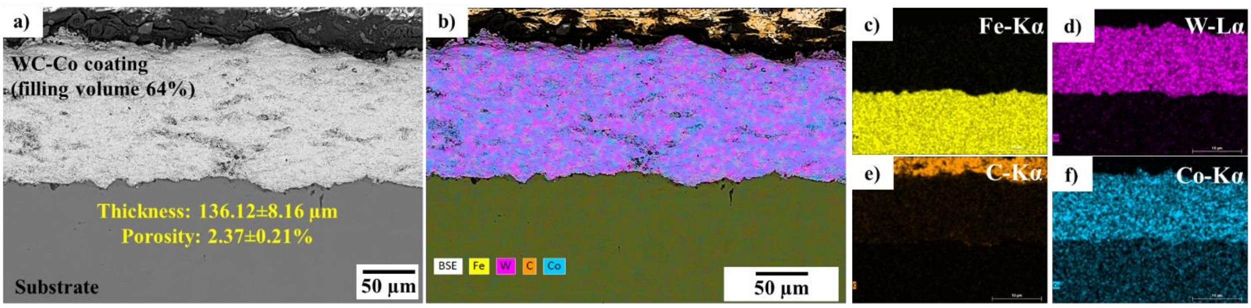


Figure 2. Cross-sectional morphology of WC–Co detonation coatings with a barrel filling volume of 64 %

The cross-sectional morphology of the WC–Co coating, produced by detonation spraying at a barrel fill volume of 64 %, reveals the formation of a dense structure with a uniform thickness of approximately 136 µm. The BSE image clearly shows a distinct substrate–coating boundary, free of microcracks and defects, indicating high adhesion. EDS mapping reveals a uniform distribution of tungsten, carbon, and cobalt throughout the coating. This structure indicates stable detonation spraying and effective fusion of WC–Co particles, ensuring the formation of a dense and uniform protective layer.

The cross-sectional morphology of the WC–Co detonation coating at a barrel fill volume of 74 % demonstrates the formation of a denser and more uniform layer compared to the 64 % regime (Fig. 3). The coating thickness increases to ~161 µm, while porosity decreases, indicating more complete melting and compaction of the particles under conditions of increased barrel fill volume. The BSE image shows a uniform lamellar structure without pronounced defects, and the interface between the substrate and the coating remains smooth and well-welded. EDS mapping results confirm a uniform distribution of the main elements — W, C, and Co — throughout the coating volume, without localized zones of WC enrichment or degradation. The absence of Fe diffusion into the coating layer indicates the absence of overheating and a stable thermal regime. Overall, the coating obtained at a barrel fill volume of 74 % is characterized by high density, good adhesion, and an optimal microstructure for operation under conditions of intense wear.

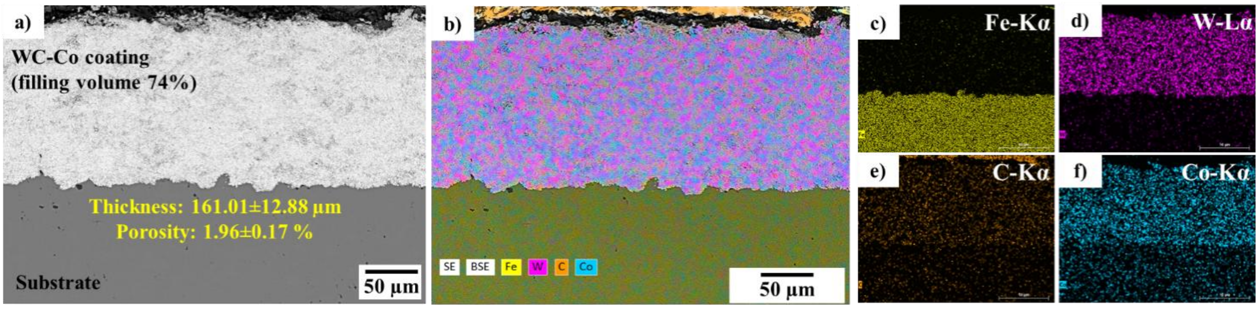
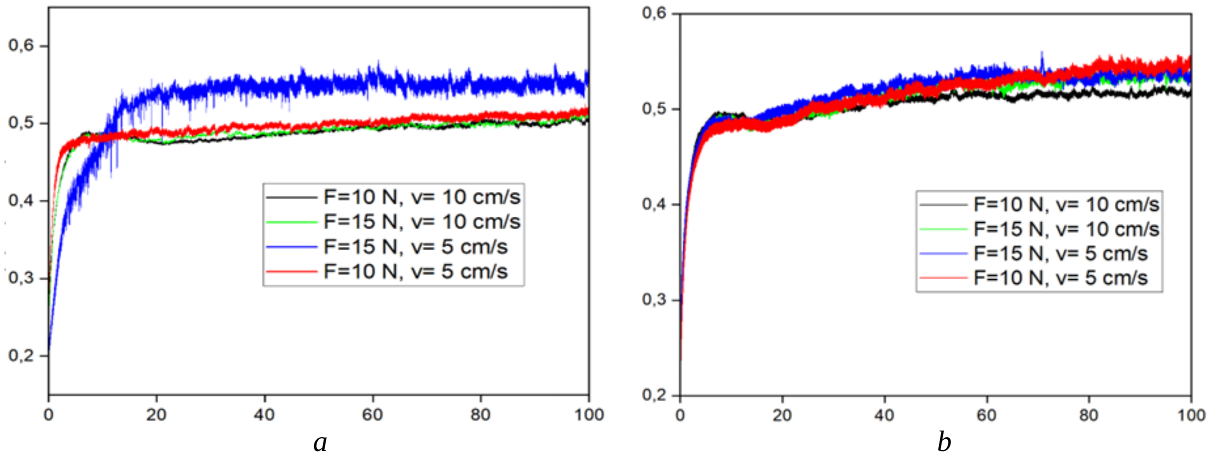


Figure 3. Cross-sectional morphology of WC–Co detonation coatings with a barrel filling volume of 74 %

Figure 4 shows the results of tribological tests of WC-Co detonation coatings at barrel fill volumes of 64 % and 74 %. Both coatings were tested in four different modes.



0x axis — friction path, m; *0y* axis — friction coefficient

Figure 4. Results of tribological tests of WC–Co detonation coatings
with a barrel filling volume of 64 % (*a*) and 74 % (*b*)

The friction coefficient versus friction path curve (Figure 2) shows that the coating obtained at a 64 % fill volume (left) exhibits more pronounced instability of the friction coefficient and an increased level of oscillations, especially at low speed (5 cm/s) and a load of 10 N, where the coefficient reaches maximum values of ~0.47–0.52. This indicates a less dense structure and increased sensitivity to local surface microroughness. At the same time, the coating at 74 % fill volume (right) exhibits more stable behavior: the amplitude of friction oscillations is noticeably lower, and the average friction coefficient for all load and speed modes remains in the range of 0.47–0.49 without sharp jumps. This stability is explained by the higher density and lower porosity of the coating, which reduces the likelihood of local deformation and promotes the formation of a more uniform contact pair. Thus, increasing the barrel filling volume to 74 % improves the wear resistance and friction stability of the WC–Co coating due to a denser and more uniform structure.

Table 1 presents the results of tribological tests of WC–Co detonation coatings with a filling volume of 64 % and 74 %. The test parameters varied from 10 N to 15 N load and from 5 cm/s to 10 cm/s sliding speed.

Table 1

Results of tribological tests

Sample	Test parameters	CoF	Wear intensity, $W_v \times 10^{-4}$, mm^3/(m·N)	V, mm^3
WC–Co 64 %	F=10 N, v= 5 cm/s	0.468	7.546	4.0044
	F=10 N, v= 10 cm/s	0.475	12.7	6.7431
	F=15 N, v= 5 cm/s	0.471	6.908	6.1104
	F=15 N, v= 10 cm/s	0.528	7.511	5.9800
WC–Co 74 %	F=10 N, v= 5 cm/s	0.486	8.327	4.4188
	F=10 N, v= 10 cm/s	0.473	7.154	3.7968
	F=15 N, v= 5 cm/s	0.490	7.194	5.7262
	F=15 N, v= 10 cm/s	0.477	4.162	3.3135

The tabulated data show how friction loading parameters affect the tribological properties of WC–Co coatings produced with different barrel fill volumes. For a coating with a 64 % fill volume, the friction coefficient ranges from 0.468 to 0.528, accompanied by relatively high wear intensity (6.908–12.7×10^{-4} mm³/(m·N)) and increased worn surface volume (4.004–6.743 mm^3). Increasing the barrel filling volume to 74 % results in a comparable friction coefficient (0.473–0.490), but significantly reduces the wear intensity to 4.162–8.327×10^{-4} mm³/(m·N) and the wear volume to 3.313–5.726 mm^3. Thus, increasing the filling volume to 74 % results in a denser, more wear-resistant coating structure, leading to a significant reduction in wear volume and area under similar friction conditions.

Conclusion

Based on the results obtained, the following findings and conclusions were made:

– The cross-sectional morphology of the WC–Co coating at 64 % and 74 % barrel fill rates demonstrate a uniform and dense structure. It is evident that the coating thickness at 74 % (~161 μm) is greater than at 64 % (~136 μm). The SEM image clearly shows a distinct substrate–coating boundary, free of microcracks and defects, indicating good adhesion. EDS mapping demonstrates that the elements confirm a uniform distribution of the main elements — W, C, and Co throughout the coating, without localized zones of WC enrichment or degradation.

– X-ray diffraction analysis of detonation coatings and WC–Co powder revealed the presence of primary peaks corresponding to the WC phase in both the original powder and the coatings. The absence of W_2C and metallic W phases indicates that no thermal decomposition of WC occurred under the selected conditions, and, therefore, the spraying process occurred under optimal conditions for temperature and particle residence time in the plasma.

Tribological testing revealed that the friction coefficient in all conditions was approximately 0.5. This demonstrates the wear-resistant properties of WC–Co coatings. However, the coatings obtained at 74 % barrel fill demonstrated a more stable friction coefficient-distance curve.

Thus, the obtained data show that detonation coatings obtained at 74 % barrel filling have a denser structure and improved tribological characteristics compared to coatings obtained at 64 %.

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References

1 Wood, R.J. (2010). Tribology of thermal sprayed WC–Co coatings. *International Journal of Refractory Metals and Hard Materials, 28*(1), 82–94.

2 Houdková, Š., Zahálka, F., Kašparová, M., & Berger, L.M. (2011). Comparative study of thermally sprayed coatings under different types of wear conditions for hard chromium replacement. *Tribology Letters, 43*(2), 139–154.

3 Yuan, J., Ma, C., Yang, S., Yu, Z., & Li, H. (2016). Improving the wear resistance of HVOF sprayed WC-Co coatings by adding submicron-sized WC particles at the splats' interfaces. *Surface and Coatings Technology, 285,* 17–23.

4 Luo, X.T., Li, C.X., Shang, F.L., Yang, G.J., Wang, Y.Y., & Li, C.J. (2015). WC-Co composite coating deposited by cold spraying of a core-shell-structured WC-Co powder. *Journal of Thermal Spray Technology, 24*(1), 100–107.

5 Ahmed, R., Ali, O., Berndt, C.C., & Fardan, A. (2021). Sliding wear of conventional and suspension sprayed nanocomposite WC-Co coatings: an invited review. *Journal of Thermal Spray Technology*, *30*(4), 800–861.

6 Du, H., Hua, W., Liu, J., Gong, J., Sun, C., & Wen, L. (2005). Influence of process variables on the qualities of detonation gun sprayed WC–Co coatings. *Materials Science and Engineering: A*, *408*(1-2), 202–210.

7 Yuan, J., Ma, C., Yang, S., Yu, Z., & Li, H. (2016). Improving the wear resistance of HVOF sprayed WC-Co coatings by adding submicron-sized WC particles at the splats' interfaces. *Surface and Coatings Technology*, *285*, 17–23.

8 Buitkenov, D., Rakhadilov, B., Nabioldina, A., Mukazhanov, Y., Adilkanova, M., & Raisov, N. (2024). Investigation of Structural Phase, Mechanical, and Tribological Characteristics of Layer Gradient Heat-Protective Coatings Obtained by the Detonation Spraying Method. *Materials*, *17*(21), 5253.

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Детонациялық бүрку режимінің WC-Co жабындарының құрылымы мен трибологиялық қасиеттеріне әсері

Мақалада оқпанды толтыру көлемі 64 % және 74 % болатын WC–Co детонациялық жабындарының құрылымы мен трибологиялық сынақтарының зерттеу нәтижелері келтірілген. WC–Co жабынының рентгендік дифракциялық талдауы детонациялық бүркуден кейін жағымсыз Co және W_2C шыңдарының жойылатынын көрсетті. Морфологиялық талдау көрсеткендей, детонациялық оқпанның 64 % және 74 % толтырылуымен жабындар сәйкесінше қалыңдығы 136 мкм және 161 мкм болатын тығыз құрылымға ие болды. ЭДС-ны картаға түсіру элементтердің біркелкі таралуын көрсетті. Қаптаманың трибологиялық сынақтары үлгілердің үйкеліс коэффициенті 74 % үшін 0,48-ден 0,53-ке дейін және 64 % үшін 0,55–0,57 аралығында болғанын көрсетті. Алынған нәтижелерге сүйене отырып, детонациялық бүрку арқылы тозуға төзімді WC–Co жабындарын алудың оңтайлы технологиялық режимі анықталды.

Кілт сөздер: детонациялық бүрку, WC–Co жабындары, трибология, жабындар, микроқұрылым

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Влияние режима детонационного напыления на структуру и трибологические свойства покрытий WC-Co

В статье представлены результаты исследования структуры и трибологические испытания детонационных покрытий WC–Co при объеме заполнения ствола 64 % и 74 %. Рентгенодифракционный анализ покрытий WC–Co выявил, что после детонационного напыления исчезают нежелательные пики Co и W_2C. Морфологический анализ показал, что при заполнении детонационного ствола 64 % и 74 % покрытия имели плотную структуру с толщиной 136 мкм и 161 мкм соответственно. ЭДС-картирование показало равномерное распределение элементов. По результатам трибологических испытаний покрытий выявлено, что коэффициент трения образцов варьировался от 0,48 до 0,53 для 74 % и от 0,55–0,57 для 64 %. На основе полученных результатов был установлен оптимальный технологический режим для получения износостойкого покрытия WC-Co методом детонационного напыления.

Ключевые слова: детонационное напыление, WC-Co покрытия, трибология, покрытия, микроструктура

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