

DOI: <https://doi.org/10.37434/tpwj2025.06.04>

# DETONATION SPRAYING OF COATINGS CONTAINING $\text{Cr}_2\text{AlC}$ MAX PHASE

**N.V. Vigilianska<sup>1</sup>, T.V. Tsymbalista<sup>1</sup>, K.V. Iantsevitch<sup>1</sup>, A.I. Kildiy<sup>1</sup>, O.Yo. Gudymenko<sup>2</sup>**<sup>1</sup>E.O. Paton Electric Welding Institute of the NASU

11 Kazymyr Malevych Str., 03150, Kyiv, Ukraine

<sup>2</sup>V.E. Lashkaryov Institute of Semiconductor Physics of the NASU

41 Nauky Prosp., 03028, Kyiv, Ukraine

**ABSTRACT**

The paper investigates the process of forming coatings containing  $\text{Cr}_2\text{AlC}$  MAX phase by detonation spraying using powders produced by the mechanochemical synthesis. The powder mixtures of the Cr–Al–C and  $\text{Cr}_3\text{C}_2$ –Al systems were used as starting components. It has been found that no new phases are formed in the Cr–Al–C system as a result of mechanochemical synthesis within 1.5–5 h, while the synthesis of  $\text{Cr}_2\text{AlC}$  MAX phase occurs during the detonation spraying of the MChS powder of this mixture. In the  $\text{Cr}_3\text{C}_2$ –Al system, the formation of  $\text{Cr}_2\text{AlC}$  MAX phase is observed already at the processing stage after 1.5 h. Due to the interaction reaction of the components in the process of detonation spraying, the content of MAX phase grows in the coating relative to the MChS powder. Both types of coatings contain phases of chromium carbides and oxide components of chromium and aluminium. The produced coatings are characterized by high microhardness (about 5000 MPa), dense lamellar structure, and corrosion resistance in a 3 % NaCl solution.

**KEYWORDS:** MAX phase, detonation spraying, coating, microstructure, corrosion resistance**INTRODUCTION**

In recent years, materials based on MAX phases have attracted increased interest for industrial use due to their unique combination of both metal and ceramic properties, which they owe to their typical nanolaminate structure [1, 2]. Among the currently known MAX phases,  $\text{Cr}_2\text{AlC}$  phase is of considerable interest due to its complex of physical and chemical properties, namely: low density, excellent mechanical properties, high rigidity, ease of processing, resistance to damage, corrosion resistance in many salt and acid solutions, electrical and thermal conductive properties [3–6]. Among the methods for producing  $\text{Cr}_2\text{AlC}$  MAX phase, the most common are sintering methods, including spark plasma sintering, hot pressing, methods of self-propagating high-temperature synthesis (SHS), and mechanochemical synthesis [7–11]. Powders of both simple elements as well as compounds of carbides, oxides, and intermetallics in various ratios are used as starting components. The produced materials have high strength, heat resistance and corrosion resistance.

Another method of using materials based on MAX phases is their depositing on the surface of parts in the form of coatings. Most of the available studies are devoted to the formation of coatings based on  $\text{Cr}_2\text{AlC}$  MAX phase in the form of thin films produced by magnetron sputtering of individual elements or segmented composite targets [12, 13]. Despite the high purity and density of magnetron coatings, they cannot be used in extreme conditions under high loads due to their small thickness, which is several microns.

To produce coatings based on MAX phases with a thickness of several hundred micrometers, thermal spraying methods such as plasma-arc, high-velocity oxygen fuel, and cold gas-dynamic spraying are used [14]. The raw materials used for spraying are powders with a synthesized  $\text{Cr}_2\text{AlC}$  MAX phase produced by sintering [15] and powders of mechanical mixtures of the starting components, such as Cr + Al + graphite [16],  $\text{Cr}_3\text{C}_2$  + Al + Cr [17]. When using powders containing MAX phase for spraying, due to the oxidation of powder particles and decomposition reactions associated with incongruent melting of MAX phases, the content of  $\text{Cr}_2\text{AlC}$  MAX phase in the coatings is significantly reduced relative to the starting powder, which is one of the main problems when spraying this type of coatings. In the case of spraying powders of mechanical mixtures, the synthesis of MAX phase occurs during the spraying process and the formation of the coating layer at the interaction of starting components. The content of MAX phase in such coatings can be further increased by the following heat treatment [16].

**THE AIM**

of this work is to study the formation of coatings containing  $\text{Cr}_2\text{AlC}$  MAX phase under the conditions of the detonation spraying method using powders produced by the mechanochemical synthesis.

**MATERIALS AND RESEARCH PROCEDURES**

Powders produced by the method of mechanochemical synthesis (MChS) of powder mixtures of 73Cr–19Al–8C and 91 $\text{Cr}_3\text{C}_2$  + 9Al (wt.%) compo-

**Table 1.** Characteristics of starting powders of mechanical mixtures

Powder	Grade	Particle size, $\mu\text{m}$	Impurity content, wt. %
Cr	PKh1M	<20	0.009 N; 0.07 C; 0.20 Fe; 0.10 Ni; 0.10 Si; 0.10 Ca; 0.30 O; P i 0.032 O
Al	PA-4	40–50	<0.4 Si, <0.35 Fe, <0.02 Cu
Graphite	GL-1	<40	Ash content <13 %
$\text{Cr}_3\text{C}_2$	PKKh-1S	<40	–

sitions were used as materials for spraying coatings by the detonation method. The characteristics of the starting powders used to produce the mechanical mixtures for the MChS process are given in Table 1.

The ratio of the components of the Cr–Al–C powder mixture was calculated to produce  $\text{Cr}_2\text{AlC}$  MAX phase according to the reaction  $2\text{Cr} + \text{Al} + \text{C} = \text{Cr}_2\text{AlC}$ ; the components of the  $\text{Cr}_3\text{C}_2$ –Al mixture were calculated on the basis of a thermodynamic assessment of the probability of reactions in the system with the formation of  $\text{Cr}_2\text{AlC}$  MAX phase and previous studies of the formation of  $\text{Cr}_2\text{AlC}$  MAX phase under plasma-arc spraying of  $\text{Cr}_3\text{C}_2$ –Al system powders [18].

The MChS process of powder mixtures was carried out in a high-energy planetary mill “Activator 2SL” at a drum rotation speed of 1000/1500 rpm, the processing time was 1.5 and 5 h.

For coating spraying, a detonation spraying unit “Perun-S” was used. A mixture of oxygen and propane-butane with the addition of air was used as a detonation mixture, the flow rate and ratio of oxygen to propane-butane was 3:1, the amount of powder per shot was  $\approx 100$  mg, and the number of shots was 100, the cycle frequency was  $6.6 \text{ s}^{-1}$ . The technological parameters of detonation spraying, such as propane-butane fuel gas flow rate ( $Q_{\text{C}_3\text{H}_8}$ ), oxygen flow rate ( $Q_{\text{O}_2}$ ), diluent gas flow rate (air) ( $Q_{\text{air}}$ ), transport gas flow rate (air) ( $Q_{\text{tr}}$ ), and spraying distance ( $L$ ), are given in Table 2. The technological parameters of detonation spraying were selected based on the calculation of obtaining a coating thickness of 4–6  $\mu\text{m}$  for 1 cycle and minimizing the oxidation of the powder material during the spraying process.

A Neophot-32 optical microscope with a digital photography device was used to study the particle microstructure of MChS powders and sprayed coatings. The phase composition of the powder and coating particles was studied using a PANalytical X’Pert PRO diffractometer with  $\text{CuK}_\alpha$ -radiation

**Table 2.** Technological parameters of detonation spraying of coatings containing  $\text{Cr}_2\text{AlC}$  MAX phase

Gas flow rate, $\text{m}^3/\text{h}$				$L$ , mm
$Q_{\text{C}_3\text{H}_8}$	$Q_{\text{O}_2}$	$Q_{\text{air}}$	$Q_{\text{tr}}$	
0.5	1.55	0.4	0.5	110

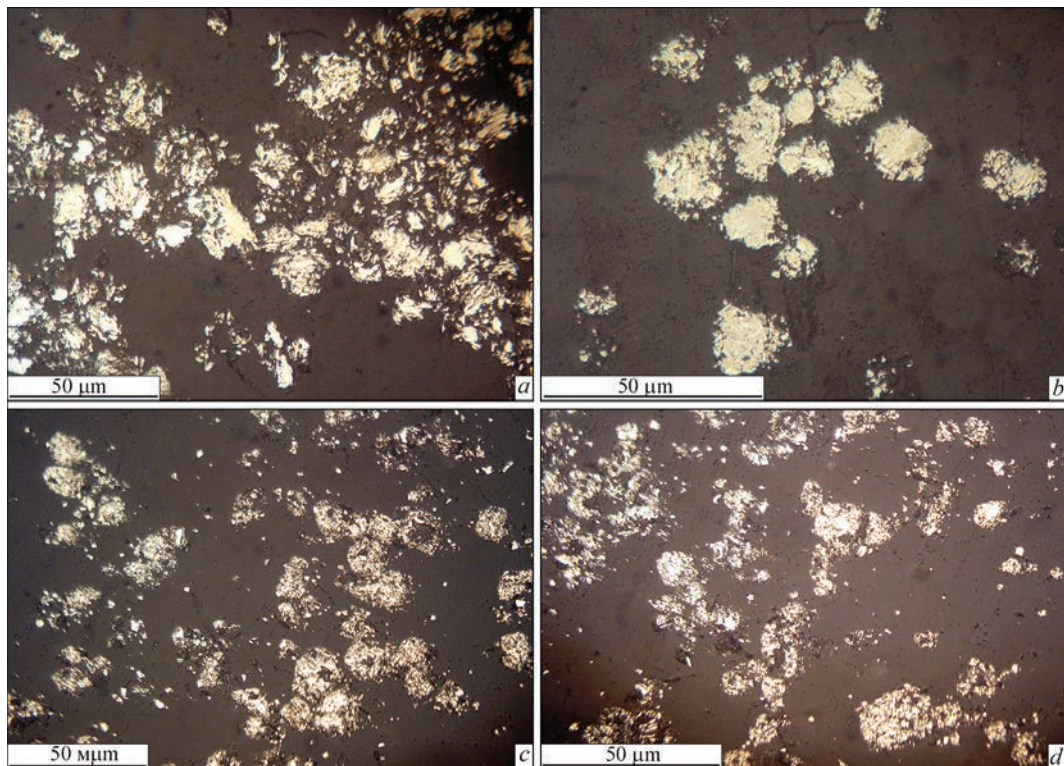
( $\lambda = 0.15406 \text{ nm}$ ). The voltage at the tube anode was 45 kV and the current was 40 mA. Diffraction patterns were taken in a step of  $0.025^\circ$  with a point accumulation time of 1 s. The diffractometric measurements data were processed using High Score Plus software. The microhardness  $HV$  of the coatings was measured using a PMT-3 microhardness tester at an indenter load of 50 g.

The corrosion resistance of the coatings was studied using the potentiostatic method. The coatings with a thickness of 500  $\mu\text{m}$  were deposited on the specimens of AISI 1017 steel with dimensions of  $50 \times 50 \times 3$  mm. Electrochemical studies were carried out in a P-5827M potentiostat with a scan rate of 2 mV/s at a temperature of 18–20  $^\circ\text{C}$ . The specimens under study were used as working electrodes, a chlorosilver electrode (Ag/AgCl) was used as a comparison electrode, and platinum was used as an auxiliary electrode. The study was carried out in a 3% NaCl solution. The current and corrosion potential were determined graphically from polarization curves.

## RESEARCH RESULTS AND DISCUSSION

The analysis of the microstructure of the powders of Cr–Al–C and  $\text{Cr}_3\text{C}_2$ –Al systems (Figure 1) indicates the formation of conglomerate-type particles of irregular shape in the MChS process due to the repeated processes of refinement and “cold welding”: both after 1.5 h and after 5 h of processing. The size of the powders of MChS products after 1.5 h of processing is  $d_{10} = 9 \mu\text{m}$ ,  $d_{50} = 21 \mu\text{m}$ ,  $d_{90} = 43 \mu\text{m}$  for Cr–Al–C system and  $d_{10} = 8 \mu\text{m}$ ,  $d_{50} = 17 \mu\text{m}$ ,  $d_{90} = 45 \mu\text{m}$  for  $\text{Cr}_3\text{C}_2$ –Al system. When the processing time is increased to 5 hours, the size of the MChS products does not change significantly and is  $d_{10} = 10 \mu\text{m}$ ,  $d_{50} = 21 \mu\text{m}$ ,  $d_{90} = 41 \mu\text{m}$  for Cr–Al–C system and  $d_{10} = 8 \mu\text{m}$ ,  $d_{50} = 16 \mu\text{m}$ ,  $d_{90} = 40 \mu\text{m}$  for  $\text{Cr}_3\text{C}_2$ –Al system.

It was found by X-ray diffraction analysis (XRD) that during the MChS process for 1.5 and 5 h of Cr–Al–C system powder, no new phases were synthesized, and only the peaks of the chromium and aluminum phases were present on the XRD patterns of the produced powders (Figure 2, *a, b*). The graphite phase was not revealed in the XRD patterns, which may be the result of its transition to an amorphous state or refinement in the mill during processing to a nanosize.



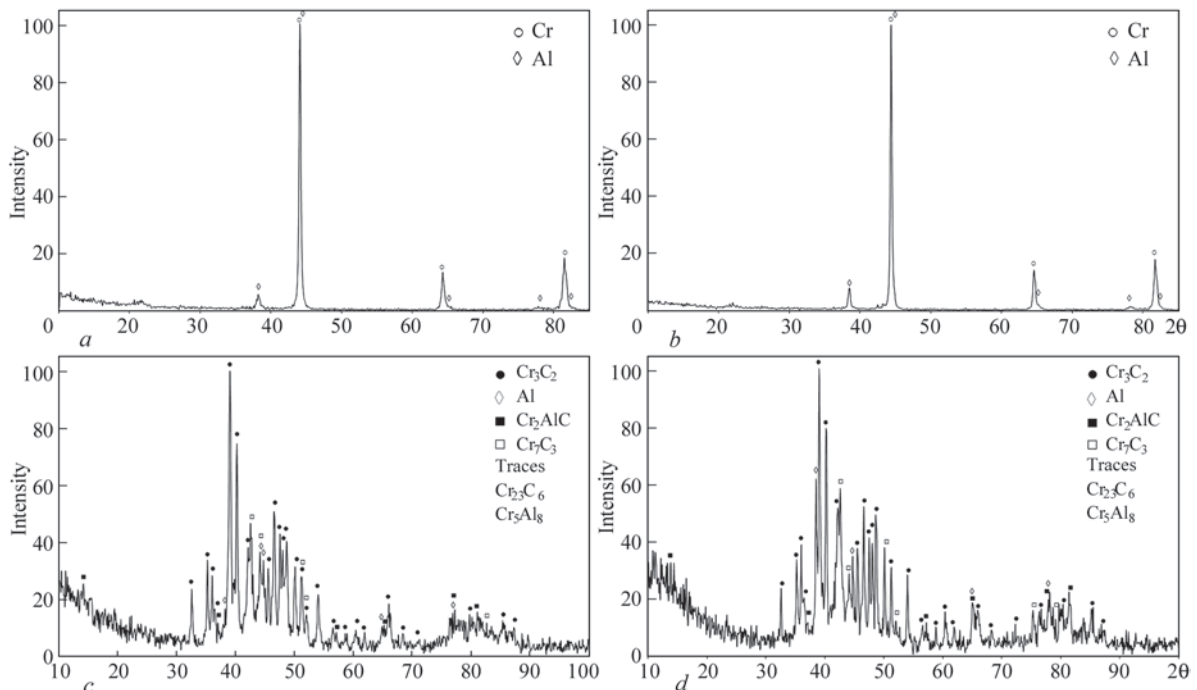
**Figure 1.** Microstructure of powders of Cr–Al–C (*a, b*) and  $\text{Cr}_3\text{C}_2$ –Al (*c, d*) systems produced by the MChS method for 1.5 (*a, c*) and 5 (*b, d*) h

With an increase in the processing time to 5 h, a slight shift towards lower angles of the chromium lines is observed, which may indicate the dissolution of aluminium in chromium to form a solid solution.

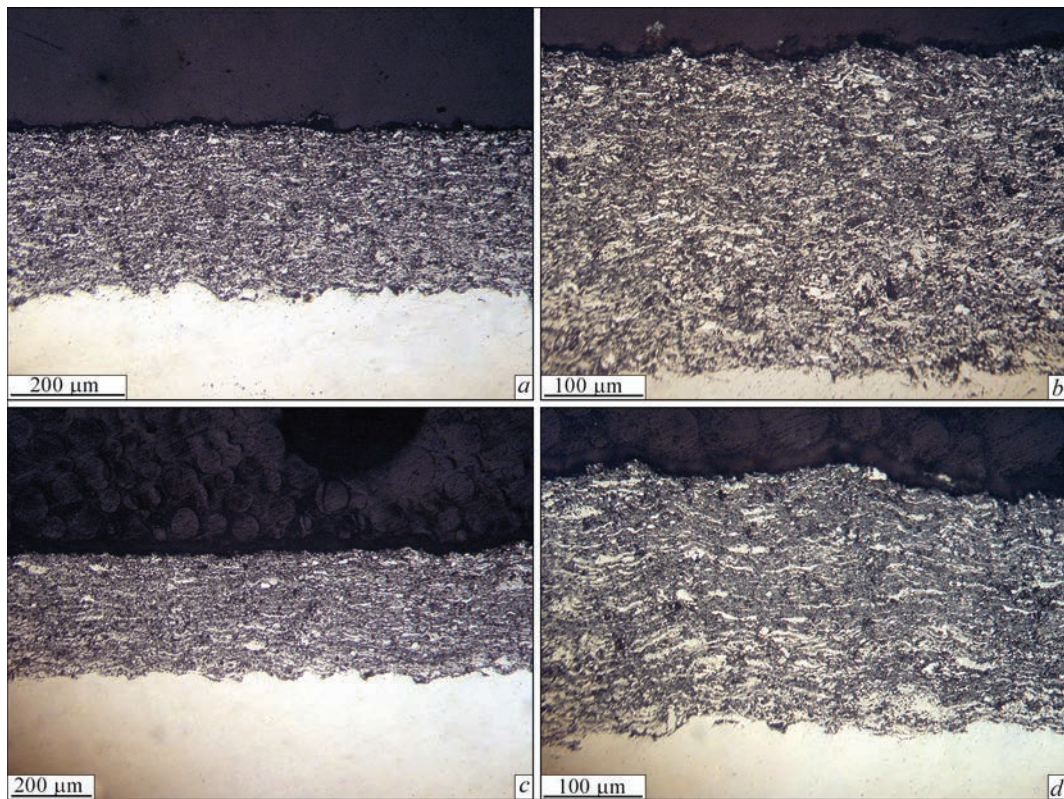
In the case of  $\text{Cr}_3\text{C}_2$ –Al system powder, during the MChS process, both at 1.5 and 5 h of processing, the starting components of the mixture of chromium and aluminium carbide interact with the formation of

$\text{Cr}_2\text{AlC}$  MAX phase and a small amount of the intermetallic  $\text{Cr}_5\text{Al}_8$  compound in the final product of the MChS phase (Figure 2, *c, d*). In addition to the starting components  $\text{Cr}_3\text{C}_2$  and Al, as well as  $\text{Cr}_7\text{C}_3$  and  $\text{Cr}_{23}\text{C}_6$  carbides are present in the powders.

Since the phase composition of the produced MChS powders does not differ significantly during processing for 1.5 and 5 h, further MChS powders



**Figure 2.** X-ray diffraction patterns of powders of Cr–Al–C (*a, b*) and  $\text{Cr}_3\text{C}_2$ –Al (*c, d*) systems produced by the MChS method for 1.5 (*a, c*) and 5 (*b, d*) h



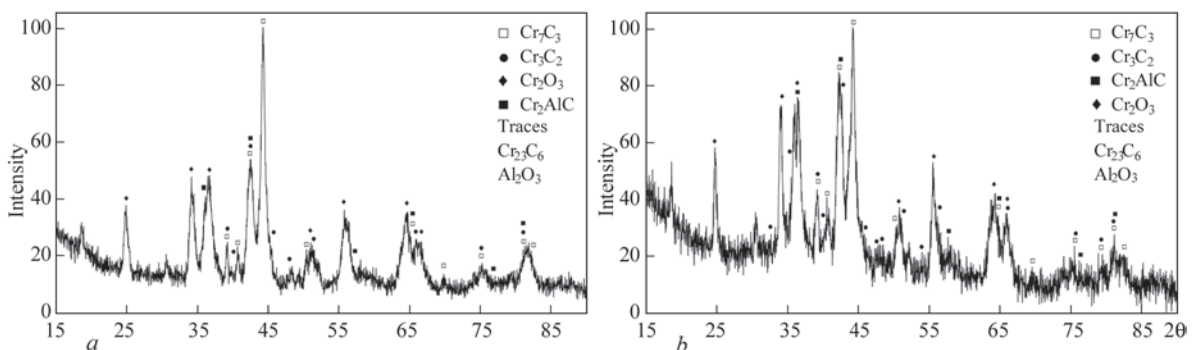
**Figure 3.** Microstructure of detonation spray coatings produced from MChS powders: *a, b* — Cr–Al–C; *c, d* — Cr<sub>3</sub>C<sub>2</sub>–Al

of Cr–Al–C and Cr<sub>3</sub>C<sub>2</sub>–Al systems produced within 1.5 h of processing were used to study the formation of coatings under detonation spraying conditions.

As a result of the detonation spraying of the produced MChS powders, dense coatings with a thin-lamellar structure are formed consisting of alternating light and dark grey oxide lamellae (Figure 3). The amount of the oxide component in Cr–Al–C coating is ~35 %, the porosity is ~7 %; in Cr<sub>3</sub>C<sub>2</sub>–Al coating — ~30 % and 4 %, respectively. The microhardness of Cr–Al–C and Cr<sub>3</sub>C<sub>2</sub>–Al coatings is 4910±1150 and 5030±1015 MPa, respectively. The presence of a large discrepancy of microhardness values in the range of 3000–10000 MPa is associated with the presence of heterogeneous phases in the coating.

The main phases in the sprayed coatings of Cr–Al–C and Cr<sub>3</sub>C<sub>2</sub>–Al systems are chromium carbide phases in the quantitative ratio according to the inten-

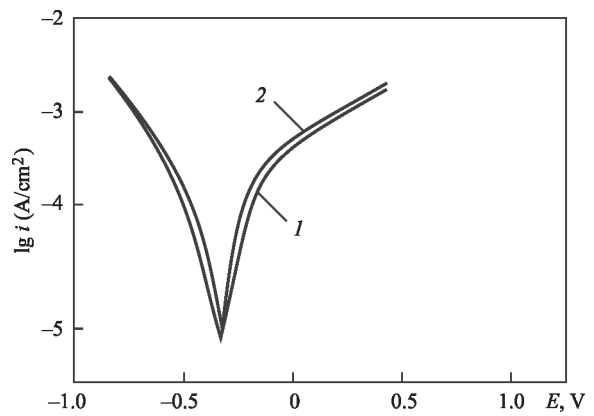
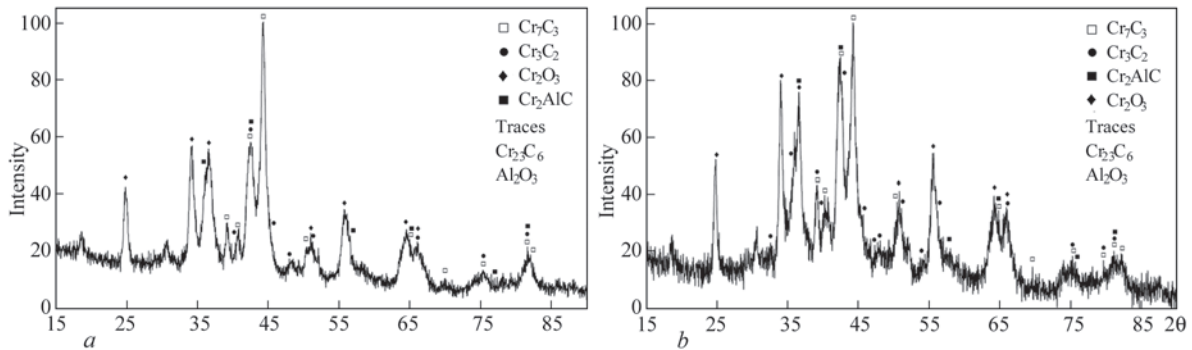
sity of the peaks: Cr<sub>7</sub>C<sub>3</sub> > C<sub>3</sub>C<sub>2</sub> > Cr<sub>23</sub>C<sub>6</sub> (Figure 4). In the case of spraying a coating of Cr–Al–C system, the appearance of chromium carbides is predetermined by the interaction of the starting components of chromium powder and graphite during the spraying process. In the case of spraying Cr<sub>3</sub>C<sub>2</sub>–Al coating, the appearance of a significant amount of Cr<sub>7</sub>C<sub>3</sub> carbide is predetermined by the partial transformation of Cr<sub>3</sub>C<sub>2</sub> carbide during the spraying process under the influence of temperature and the interaction of powder particles with ambient oxygen. The coatings contain a significant amount of chromium oxide Cr<sub>2</sub>O<sub>3</sub> and a small amount of aluminium oxide Al<sub>2</sub>O<sub>3</sub> of the corundum modification. In contrast to MChS powders, the coatings do not contain a pure aluminium phase, which indicates its complete interaction during the spraying process with the components of Cr, C, Cr<sub>3</sub>C<sub>2</sub> powders and ambient oxygen. Both types of coat-



**Figure 4.** X-ray diffraction patterns of detonation spray coatings of Cr–Al–C (*a*) and Cr<sub>3</sub>C<sub>2</sub>–Al (*b*) systems

**Table 3.** Electrochemical characteristics of Cr–Al–C and Cr<sub>3</sub>C<sub>2</sub>–Al detonation spray coatings in a 3 % NaCl solution

Material	$E_{st}$ , V	$E_c$ , V	$i_c$ , A/cm <sup>2</sup>
Cr–Al–C DS coating	–0.40	–0.36	$2.0 \cdot 10^{-6}$
Cr <sub>3</sub> C <sub>2</sub> –Al DS coating	–0.44	–0.38	$1.6 \cdot 10^{-6}$
Steel 3	–0.54	–0.52	$2.4 \cdot 10^{-5}$
40Kh13	–0.28	–0.26	$2.0 \cdot 10^{-6}$
12Kh18M10T	–0.16	–0.18	$1.6 \cdot 10^{-6}$


**Figure 5.** Polarization curves of detonation coatings in a 3 % NaCl solution: 1 — Cr–Al–C; 2 — Cr<sub>3</sub>C<sub>2</sub>–Al

**Figure 6.** X-ray diffraction patterns of detonation spray coatings of Cr–Al–C (a) and Cr<sub>3</sub>C<sub>2</sub>–Al (b) systems after electrochemical studies in a 3 % NaCl solution

ings contain Cr<sub>2</sub>AlC MAX phase, and the intensity of MAX phase peaks in Cr<sub>3</sub>C<sub>2</sub>–Al coating is significantly higher, which may indicate a greater amount of MAX phase in it. Also, an increase in the intensity of peaks corresponding to MAX phase on the XRD pattern of Cr<sub>3</sub>C<sub>2</sub>–Al coating relative to the peaks on the XRD pattern of the MChS powder is noted, which indicates the interaction of powder components during the process of detonation spraying and the formation of a coating layer with the formation of MAX phase.

The studies of the kinetics of the electrode potentials of detonation coatings of Cr–Al–C and Cr<sub>3</sub>C<sub>2</sub>–Al systems have made it possible to find that the value of the electrode potential of the specimens stabilizes after 25–30 min. The stationary potentials  $E_{st}$  are –0.4 and –0.44 V, respectively. The characteristic polarization curves of the coatings are shown in Figure 5; the electrochemical characteristics of the coatings are given in Table 3. For comparison, Table 3 also shows the characteristics of St3 and stainless steels 40Kh13 and 12Kh18N10T.

The analysis of the polarization curves showed that the course of cathodic and anodic polarization curves for detonation coatings of both compositions is almost the same. The corrosion current for Cr<sub>3</sub>C<sub>2</sub>–Al system coating is 1.25 times lower than that of Cr–Al–C system coating, which indicates its higher corrosion resistance. This is obviously predetermined by

the higher content of MAX phase in Cr<sub>3</sub>C<sub>2</sub>–Al coating and the slightly lower porosity of this coating. After electrochemical studies, the phase composition of the sputtered coatings does not change significantly (Figure 6), i.e., no corrosion processes occur on the surface of the coated specimens. The developed coatings of both compositions are not inferior to stainless steels in terms of their corrosion resistance and are by an order of magnitude higher than carbon steel.

## CONCLUSIONS

The carried out studies of the products of mechanochemical synthesis of powder mixtures of Cr–Al–C and Cr<sub>3</sub>C<sub>2</sub>–Al compositions showed the formation of conglomerate-type particles with a size in the range of  $d_{10} = 8\text{--}10$ ,  $d_{50} = 16\text{--}21$ ,  $d_{90} = 40\text{--}45$  μm after 1.5–5 h of processing. In Cr<sub>3</sub>C<sub>2</sub>–Al system, the formation of Cr<sub>2</sub>AlC MAX phase was recorded after 1.5 h of processing; in the case of Cr–Al–C system, no interaction of components with the formation of new phases occurs during the MChS process.

As a result of detonation spraying of the produced MChS powders, dense coatings with a thin-lamellar structure are formed. The presence of Cr<sub>2</sub>AlC MAX phase, as well as chromium carbides and oxide phases Cr<sub>2</sub>O<sub>3</sub> and Al<sub>2</sub>O<sub>3</sub> is recorded in the coatings. The content of MAX phase in the coatings relative to the MChS powder is higher in the coatings formed from the pow-

ders of Cr<sub>3</sub>C<sub>2</sub>-Al system; an increase in the content of MAX phase in the coating relative to the MChS powder was found due to the interaction reactions between the starting components during the spraying process.

Based on the results of potentiostatic studies in a 3 % NaCl solution, it was found that coatings based on Cr<sub>3</sub>C<sub>2</sub>-Al system are characterized by a lower corrosion current (1.6·10<sup>-6</sup> A/cm<sup>2</sup>) compared to Cr-Al-C (2.0·10<sup>-6</sup> A/cm<sup>2</sup>), which confirms their higher corrosion resistance due to the higher content of MAX phase and denser structure. The developed coatings of both compositions are not inferior to stainless steels in terms of their indices of corrosion resistance and can be recommended for operation in this aggressive environment.

## REFERENCES

- Gonzalez-Julian, J. (2020) Processing of MAX phases: From synthesis to applications. *J. of the American Ceramic Society*, 104(2), 659–690. DOI: <https://doi.org/10.1111/jace.17544>
- Sun, Z.M. (2011) Progress in research and development on MAX phases: A family of layered ternary compounds. *Inter. Materials Reviews*, 56(3), 143–166. DOI: <https://doi.org/10.1179/1743280410y.0000000001>
- Tian, W., Wang, P., Zhang, G. et al. (2007) Mechanical properties of Cr<sub>2</sub>AlC ceramics. *J. of the American Ceramic Society*, 90(5), 1663–1666. DOI: <https://doi.org/10.1111/j.1551-2916.2007.01634.x>
- Tian, W., Wang, P., Zhang, G. et al. (2006) Synthesis and thermal and electrical properties of bulk Cr<sub>2</sub>AlC. *Scripta Materialia*, 54(5), 841–846. DOI: <https://doi.org/10.1016/j.scriptamat.2005.11.009>
- Majed, R.A., Hasan, A.M., Faleh, R.F. (2015) Corrosion behavior of V<sub>2</sub>AlC and Cr<sub>2</sub>AlC materials in acidic media. *Engineering and Technology J.*, 33(4), 845–854. DOI: <https://doi.org/10.30684/etj.33.4A.8>
- Azina, C., Badie, S., Litnovsky, A. et al. (2023) Optical properties and corrosion resistance of Ti<sub>2</sub>AlC, Ti<sub>3</sub>AlC<sub>2</sub>, and Cr<sub>2</sub>AlC as candidates for concentrated solar power receivers. *Solar Energy Materials and Solar Cells*, 259, 112433. DOI: <https://doi.org/10.1016/j.solmat.2023.112433>
- Desai, V., Shrivastava, A., Zala, A.B. et al. (2024) Manufacturing of high purity Cr<sub>2</sub>AlC MAX phase material and its characterization. *J. of Mater. Eng. and Performance.*, 33, 9841–9849. DOI: <https://doi.org/10.1007/s11665-024-09513-4>
- Shamsipoor, A., Farvizi, M., Razavi, M., Keyvani, A. (2019) Influence of processing parameters on the microstructure and wear performance of Cr<sub>2</sub>AlC MAX phase prepared by spark plasma sintering method. *J. of Alloys and Compounds*, 815, 152345. DOI: <https://doi.org/10.1016/j.jallcom.2019.152345>
- Xiao, L.-O., Li, S.-B., Song, G., Sloof, W.G. (2011) Synthesis and thermal stability of Cr<sub>2</sub>AlC. *J. of the European Ceramic Society*, 31(8), 1497–1502. DOI: <https://doi.org/10.1016/j.jeurceramsoc.2011.01.009>
- Gonzalez-Julian, J., Llorente, J., Bram, M. et al. (2017) Novel Cr<sub>2</sub>AlC MAX-phase/SiC fiber composites: Synthesis, processing and tribological response. *J. of the European Ceramic Society*, 37(2), 467–475. DOI: <https://doi.org/10.1016/j.jeurceramsoc.2016.09.029>
- Yeh, C.L., Kuo, C.W. (2011) Effects of Al and Al<sub>2</sub>C<sub>3</sub> contents on combustion synthesis of Cr<sub>2</sub>AlC from Cr<sub>2</sub>O<sub>3</sub>-Al-Al<sub>4</sub>C<sub>3</sub> powder compacts. *J. of Alloys and Compounds*, 509(3), 651–655. DOI: <https://doi.org/10.1016/j.jallcom.2010.09.169>
- Field, M.R., Carlsson, P., Eklund, P. et al. (2014) A combinatorial comparison of DC and high power impulse magnetron sputtered Cr<sub>2</sub>AlC. *Surf. and Coat. Technol.*, 259, 746–750. DOI: <https://doi.org/10.1016/j.surfcoat.2014.09.052>
- Su, R., Zhang, H., Meng, X. et al. (2017) Synthesis of Cr<sub>2</sub>AlC thin films by reactive magnetron sputtering. *Fusion Engineering and Design*, 125, 562–566. DOI: <https://doi.org/10.1016/j.fusengdes.2017.04.129>
- Vihilianska, N.V., Filonenko, D.V., Yushchenko, A.O. et al. (2024) Thermal spraying of coatings, containing Cr<sub>2</sub>AlC MAX-phase (Review). *The Paton Welding J.*, 3, 24–32. DOI: <https://doi.org/10.37434/tpwj2024.03.04>
- Go, T., Sohn, Y.J., Mauer, G. et al. (2019) Cold spray deposition of Cr<sub>2</sub>AlC MAX phase for coatings and bond-coat layers. *J. of the European Ceramic Society*, 39(4), 860–867. DOI: <https://doi.org/10.1016/j.jeurceramsoc.2018.11.035>
- Zhang, F., Yan, S., Li, C. et al. (2019) Synthesis and characterization of MAX phase Cr<sub>2</sub>AlC based composite coatings by plasma spraying and post annealing. *J. of the European Ceramic Society*, 39(16), 5132–5139. DOI: <https://doi.org/10.1016/j.jeurceramsoc.2019.08.039>
- Zhang, F., Yu, G., Yan, S. et al. (2023) Characterization and reaction mechanism of in-situ micro-laminated Cr<sub>2</sub>AlC coatings by plasma spraying Cr<sub>2</sub>C/Al/Cr powder mixtures. *Surf. and Coat. Technol.*, 456, 129271. DOI: <https://doi.org/10.1016/j.surfcoat.2023.129271>
- Vigilianska, N., Iantsevitch, C., Tsymbalista, T. et al. (2024) Formation of coatings containing Cr<sub>2</sub>AlC MAX phase during plasma spraying of mixture of Cr<sub>3</sub>C<sub>2</sub>+Al powders. *Coatings*, 14(12), 1584. DOI: <https://doi.org/10.3390/coatings14121584>

## ORCID

N.V. Vigilianska: 0000-0001-8576-2095,  
T.V. Tsymbalista: 0000-0001-9569-7776,  
K.V. Iantsevitch: 0000-0002-3975-7727,  
A.I. Kildiy: 0000-0001-8133-8705,  
O.Yo. Gudymenko: 0000-0002-5866-8084

## CONFLICT OF INTEREST

The Authors declare no conflict of interest

## CORRESPONDING AUTHOR

N.V. Vigilianska  
E.O. Paton Electric Welding Institute of the NASU  
11 Kazymyr Malevych Str., 03150, Kyiv, Ukraine.  
E-mail: [pewinataliya@gmail.com](mailto:pewinataliya@gmail.com)

## SUGGESTED CITATION

N.V. Vigilianska, T.V. Tsymbalista, K.V. Iantsevitch, A.I. Kildiy, O.Yo. Gudymenko (2025) Detonation sputtering of coatings containing Cr<sub>2</sub>AlC MAX phase. *The Paton Welding J.*, 6, 25–30. DOI: <https://doi.org/10.37434/tpwj2025.06.04>

## JOURNAL HOME PAGE

<https://patonpublishinghouse.com/eng/journals/tpwj>

Received: 02.05.2025

Received in revised form: 19.05.2025

Accepted: 27.06.2025