The cold gas spraying process is the most modern method of thermal spraying. The article presents the coating produced in this process from Cr$_3$C$_2$-25(Ni20Cr) powder on the Al 7075 alloy substrate. The properties of microstructure and mechanical properties of the deposited coating are also shown. The process parameters of the applied powder allowed to obtain coatings characterized by a consistent microstructure and negligible porosity.

**KEYWORDS:** cold gas spraying, mechanical properties, coating, Cr$_3$C$_2$-25(Ni20Cr)

**Introduction**

The process of cold gas spraying makes obtaining a coating with exceptional mechanical properties and possible potential innovation. The coating properties were developed in such a way that they are not available for other methods of thermal spraying methodology [1-2].

Formation of the coating, i.e. the deposition of powder, is carried out by plastic deformation of its grains as a result of hitting the ground at high speed, at a temperature much lower than its melting point [3]. In this way, it is possible to obtain a coating with favorable compressive stresses. During the cold gas spraying process, the high energy of the powder grains when they hit the surface improves the mechanical properties of the coating [4].

The range of materials used in the cold gas spraying process includes pure metals, alloys and cermet [5-7]. Cermets are made of a metal matrix and a hard reinforcing phase. They are characterized by a number of increased mechanical properties and are used in industry due to their structural integrity and high resistance to temperature and wear. The combination of ceramic and metal phases enables higher fracture toughness [8]. Cermets coatings Cr$_3$C$_2$-25(Ni20Cr), obtained in thermal processes, have been used as anticorrosive coatings for machine elements and increasing their wear resistance [9].

Due to the cold gas spraying process, Cr$_3$C$_2$ carbides do not degrade to their lower hardness counterparts (Cr$_2$C$_3$). The use of cermets powders in the form of mixtures ensures better deposition efficiency [10]. In this process, ceramic particles do not deform plastically, but deposit in the plastic phase of the metal.

The advantage of the cold gas spraying process is that the phase composition of the powder can be preserved in the deposited coating [11]. The main factors affecting the mechanical properties of the resulting coatings and their microstructure are spraying parameters and the morphology of the powder used [12–13].

**Research methodology**

Cr$_3$C$_2$-25(Ni20Cr) coatings were applied using the Impact Innovations 5/8 cold gas spray system (fig. 1) and powder and Diamalloy 3004, Oerlikon Metco Inc., Westbury, NY, USA.
It is a mixture of Cr$_3$C$_2$ and Ni20Cr powders in a weight ratio of 75%/25% [14]. The coatings were sprayed on an Al 7075 alloy substrate onto samples of 30 mm × 400 mm × 6 mm. The parameters of the cold gas spraying process are presented in the tab. I.

A scanning electron microscope (SEM-E-SEM FEI XL 30) was used to characterize the powder morphology and their metallographic cross-sections. The topography of the coatings and the shape of the profile were tested using a Talysurf CCI-Lite contactless 3D profilograph. Indentations were carried out using a Nanovea device with a Berkovich indenter, at a load of 20 mN.

| TABLE I. Parameters of the cold gas spraying process for Cr$_3$C$_2$-25(Ni20Cr) coatings |
|---------------------------------|----------|
| Pressure, MPa                  | 4        |
| Temperature, °C                | 800      |
| Space, mm                      | 50       |
| Powder feed rate, g/min        | 95       |
| Technological gas              | N$_2$    |
| Number of layers               | 40       |

Research results and discussion

Characteristics of Cr$_3$C$_2$-25(Ni20Cr) powders. The morphology of the Cr$_3$C$_2$-25(Ni20Cr) powder is shown in fig. 2. The spray powder was made as a mixture of Cr$_3$C$_2$ and Ni20Cr powders. Cr$_3$C$_2$ powder particles have an irregular shape, while NiCr particles have a spherical shape. Fig. 3 shows a cross-sectional view of the grains of Cr$_3$C$_2$-25(Ni20Cr) powder.

Powder particles Cr$_3$C$_2$-25(Ni20Cr) are characterized by clear porosity and numerous cracks in cross-sections.
The grain size distribution of the powder is presented in fig. 4. The presence of a large fraction of fine grains is noticeable in the powder.

- **Characteristics of Cr$_3$C$_2$-NiCr coatings.** Fig. 5a and 5b show the morphology of the surface of the Cr$_3$C$_2$-25(Ni20Cr) coating obtained in the process of spraying with cold gas. Powder size distribution has changed, which is reflected in the morphology and surface roughness.
Cr$_3$C$_2$-25(Ni20Cr) coatings have a smooth surface with fine grains. Cr$_3$C$_2$ ceramic particles are much thinner on the surfaces presented than they were at the initial stage. Cracking and breaking of the Cr$_3$C$_2$ particles into smaller fragments occurred while hitting them at high speed against the embedded particles (figs. 5c and 5d). Small ceramic particles occurring in the microstructure may have the effect of limiting crack propagation [15]. Fig. 6 shows the surface topography, depth histogram and load-bearing curve. The obtained results indicate a high surface roughness (Ra of 16.3±160.3 µm). Surface topography parameters are summarized in the tab. II. The tested coating has asymmetry with a negative inclination of the surface height. The value of kurtosis was 3.2, which indicates that the surface is free of extreme peak and valley features. The results show compliance with the surface morphology (fig. 4).

Fig. 5. Surface microstructure (a, b) and specimen (c, d) of a Cr$_3$C$_2$-25(Ni20Cr) coating sprayed with cold gas

Fig. 6. Surface configuration, depth histogram with a load-bearing curve for a coating over a distance of 50 mm
To confirm the mechanical properties of cold gas sprayed Cr$_3$C$_2$-25(Ni20Cr) coatings, their hardness and Young's modulus were tested. The hardness of the obtained coating was 627 HV0.3, while the value of Young's modulus was 145.9 GPa. Fig. 7 presents the distribution map, hardness histogram and shell's Young's modulus.

**Conclusions**

The paper discusses the results of testing the mechanical properties and microstructure of the Cr$_3$C$_2$-25(Ni20Cr) coating, sprayed with cold gas on an Al 7075 substrate. The experiment allowed obtaining a compact microstructure and negligible porosity coating. During the process, plastic deformation of Ni20Cr grains occurred, while Cr$_3$C$_2$ particles were partially defragmented due to a strong impact. The surface of the obtained coating shows a noticeable roughness, which is caused by the extensive granulometric distribution of the powders used, as well as the diverse interaction of Cr$_3$C$_2$ particles on the sprayed surface.

The work was financed from funds for the National Science Center in Poland (project No. 2017/25/B/ST8/02228).

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