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Corrosion properties of cold sprayed aluminum coatings

Keywords:
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Abstract

The article presents the results of corrosion resistance tests of cold-sprayed aluminum coatings onto 4330 steel and Al 7075 aluminum alloy. The coatings were subjected to corrosion tests in a salt chamber.The obtained coatings are characterized by low porosity and very good anti-corrosion properties.

Introduction

Advances in surface engineering are associated with technologies that allow obtaining surface layers with new, increasingly better properties. Coatings and elements obtained in the thermal spraying process provide high resistance to wear, corrosion resistance, bioactivity, catalytic activity, electrical and thermal insulation and many others [1]. In the case of a thermal spray process, the basic factors are: the heat source and the speed of the molecule. Depending on these parameters, we distinguish thermal spraying such as: flame, arc, plasma, detonation, laser, supersonic (HVOF) and cold gas spraying. Due to the elimination of high-temperature processes in cold gas spraying, there is no recrystallization process, there are no phase changes and new possibilities are obtained that are not available for classic thermal spraying technologies [2].

At the turn of the 1980s, the team of Professor A. Papyrin at the Institute of Theory and Applied Mechanics in Novosibirsk developed the theoretical foundations for the cold gas spraying process. The result of the research was to obtain coatings from various metals, alloys and composites. The cold gas spraying process involves heating and introducing gas under high pressure to the de Laval nozzle. A coating material is introduced into the nozzle by a separate gas line. Helium, nitrogen, air or their mixtures are used as process gas [3].

The basic issue related to cold gas spraying is to determine the critical velocity V_{kr}, for a specific material system: coating-substrate. If the velocity of the particle is too small – it is reflected from the substrate without forming a coating. The coating is formed when the critical velocity V_k is exceeded and the particles undergo plastic deformation, which allows mechanical bonding with the substrate. At very high particle speeds, intensive substrate erosion occurs [4,5].

Corrosion of aluminum coatings sprayed with cold gas

Corrosion is the loss of material caused by interaction with the environment. Two basic approaches apply to issues related to corrosion. The first strategy covers the aspects of materials and material engineering, which threaten the design of materials at the microscopic level and their processing of the durability of the effect in a specific corrosive environment. The second approach uses the design of surface layers and their application. Coatings are applied to the base material with lesser corrosion resistance to achieve better corrosion resistance. Coating obtained by cold spraying compared to conventional thermal spraying methods provides better corrosion protection for metal, taking into account the type of corrosive environment. Obtained layers have low porosity, low oxygen content and fine-grained structure [6].

Research methodology

The coating on the test samples was mounted using the Impact Innovations 5/8 cold gas spraying system located

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at the Kielce University of Technology. Nitrogen was the working gas in this process. The tests were carried out on aluminum coatings sprayed on samples made of 4330 steel (PN-EN 4330) and aluminum alloy Al 7075 (PN PA9). Steel 4330 is an alloy steel used in aircraft chassis and heavy duty machine parts. Alloy Al 7075 is one of the most important materials used in the construction of load-bearing elements in airplanes.

The obtained coatings were tested in a salt chamber. It is a device for producing and maintaining the research environment in the form of a spraying salt mist. The tests were carried out in accordance with ASTM B117 [8]: sample exposure angle 15°, chamber temperature 35±2 °C, NaCl 4÷6% spraying concentration, assumed exposure time of the samples was 336 hours. The spraying took place in a continuous cycle, with unchanging conditions in the chamber.

The exposure time of the tested samples in the salt chamber was:

– Al/4330 (336 hours) – no red corrosion (rust),
– Al/7075 (100 hours) – the coating was fractured.

Samples were removed daily from the chamber, gently rinsed under running water at a temperature not exceeding 38 °C to remove residual salt deposits from the surface, and then dried with a stream of clean compressed air. The cleaned samples were evaluated for corrosion and other defects in accordance with the requirements of standards and instructions regarding the material or coating being tested. Samples without rust marks went into the chamber, after the appearance of rust blooms (3 dots per 1 cm^2) the samples were removed from the chamber. The microstructure of the sprayed coating was investigated using the Jeol JSM 5400 scanning microscope, the linear analysis was performed with the ISIS 300 Oxford microprobe (EDS), and the qualitative analysis of the phase composition was performed using XRD X-ray diffractometer (model PHILIPS PW 1830).

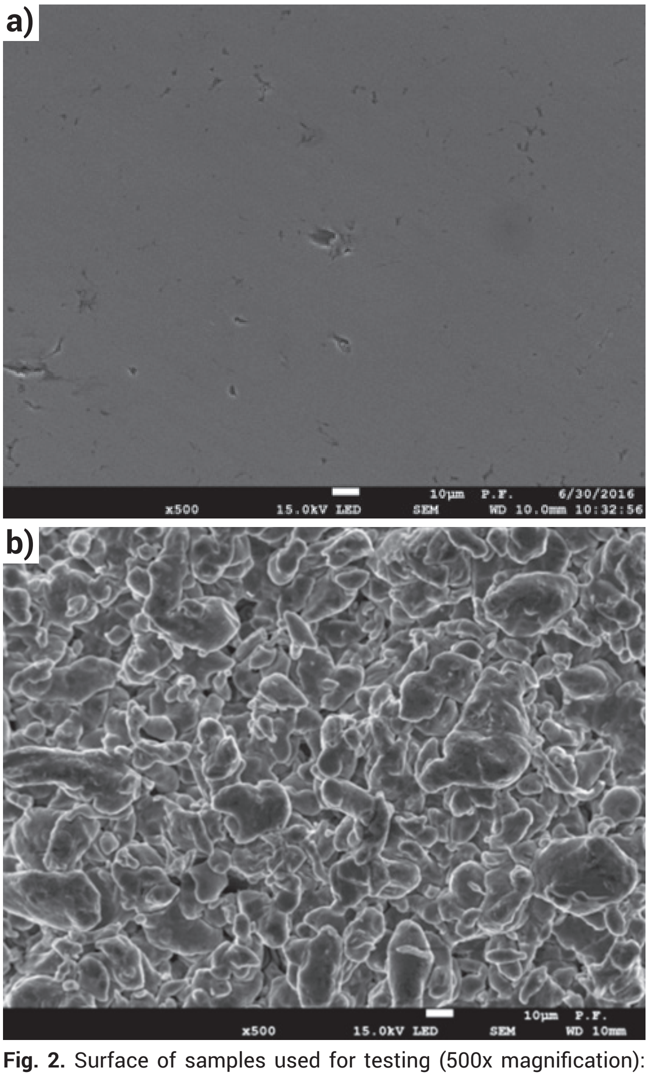


Fig. 2. Surface of samples used for testing (500x magnification): a) 4330 steel substrate, b) 7075 aluminum substrate

Research results and discussion

Figure 1 shows the morphology of Al grains. Powder (producer: Toyal Europe) had a unimodal granularity distribution. It consisted of grains of various sizes and irregular shapes. Powder parameters: d10=19 µm; d15=30.4 µm; d90=48.6 µm.

The morphology of the samples before applying the coatings is shown in Figure 2.

The substrate before spraying was subjected to vapour blasting. Surfaces of cold gas sprayed coatings after tests in the salt chamber are shown in Figure 3. The coating of a steel substrate (Fig. 3a) shows grains of Al powder with higher granulation. During spraying, they were compacted, condensed and slightly plastic deformed. The coating on the aluminum substrate (Fig. 3b) shows a very large plastic deformation of the grains with smaller granulation, while the larger grains are deformed to a much lesser extent. Their squashing results in the elimination or reduction of empty spaces in the coating, resulting in a decrease in its porosity. The fine, white, spherical grains visible on the surfaces of the samples are contamination of the powder. The obtained coatings slightly differ from the initial material morphology (Fig. 2b).

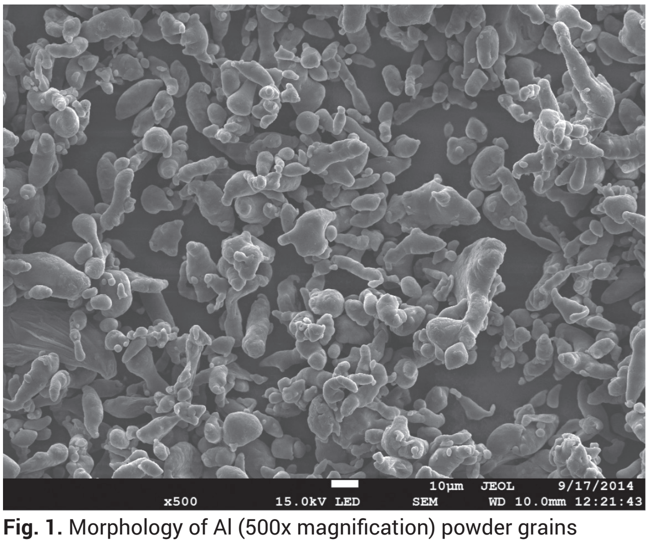


Fig. 1. Morphology of Al (500x magnification) powder grains

The analysis of the distribution of elements showed the content of aluminum as the main component and elements such as: oxygen, sodium, chlorine, potassium, calcium and chromium as residues after samples in the salt chamber, where they were subjected to bathing in a brine solution. Figures 4 and 5 present the spectrum of elements distribution analysis, the distribution of research points and the percentage distribution of elements in the tested coating on a steel substrate and aluminum.

The qualitative analysis of the phase composition of the analyzed samples in the salt chamber made by X-ray diffraction showed pure metals in the form of aluminum, without the presence of reflexions of other elements. Figure 6 shows the diffractograms of cold gas sprayed coatings on a steel substrate, aluminum and a reference sample (powder). Test parameters: range 2 theta 20÷120°, step 0.02°, exposure time 5 sec per point (250 sec per degree).

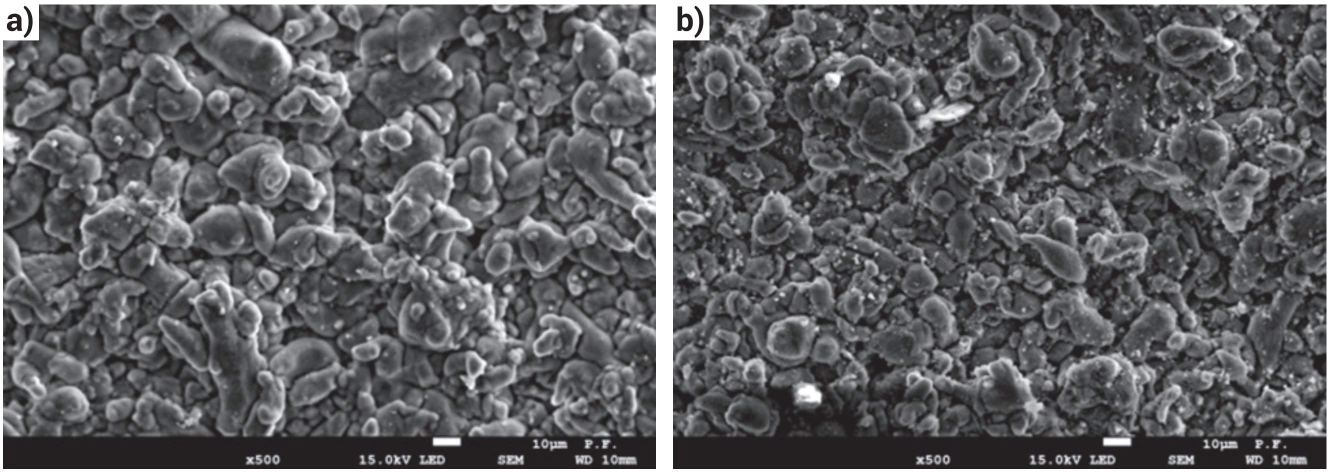
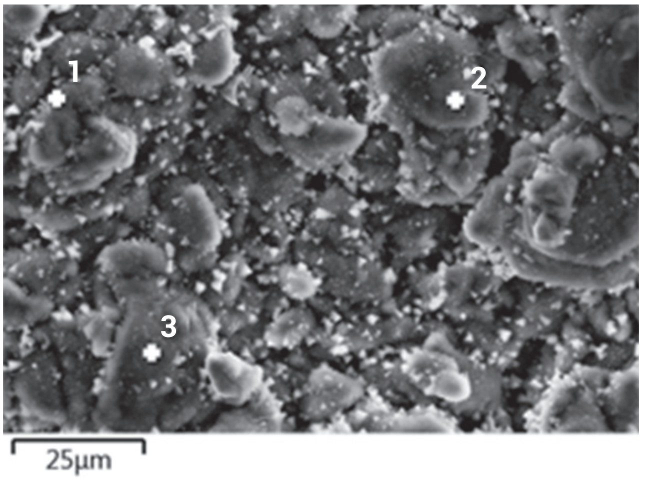
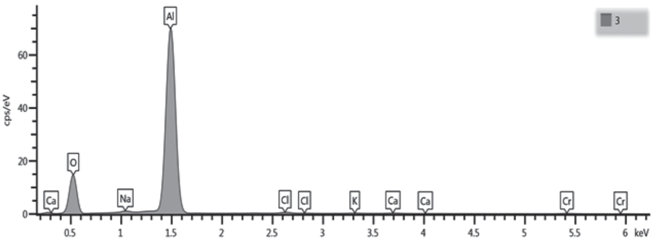


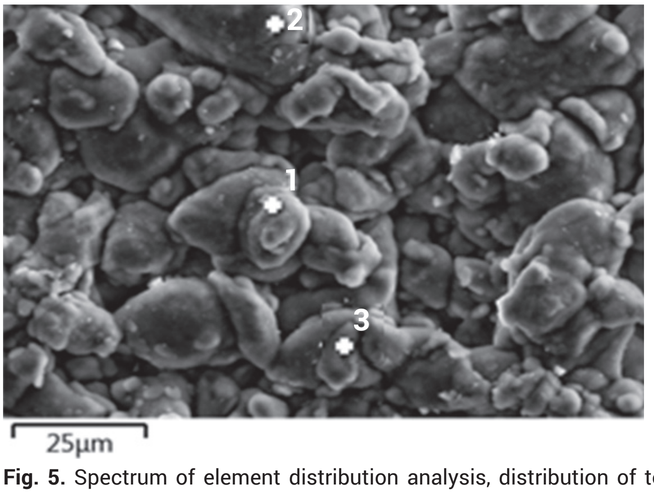
Fig. 3. Surface of aluminum coating sprayed with cold gas (500x magnification): a) on a 4330 steel substrate, b) on an Al 7075 alloy substrate

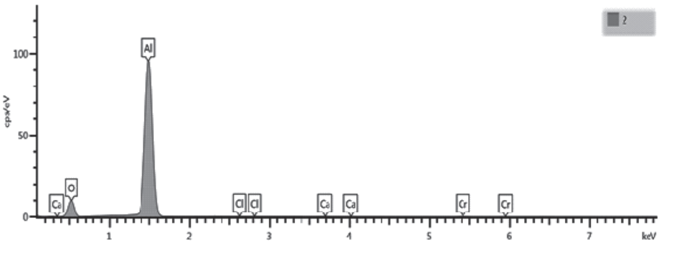




Spectrum Label	O	Na	Al	Cl	K	Ca	Cr
1	19,4	0,96	77,39	0,63	0,21	0,28	0,51
2	30,52	0,32	67,86	0,34	0,15	0,23	0,59
3	30,18	0,53	67,51	0,71	0,19	0,29	0,60
średnia	26,70	0,60	70,92	0,56	0,18	0,27	0,57

Fig. 4. Spectrum of element distribution analysis, distribution of test points, percentage distribution of elements in the tested coating on a steel substrate





Spectrum Label	O	Al	Cl	Ca	Cr
1	14,90	84,08	0,22	0,18	0,62
2	14,59	84,15	0,21	0,18	0,87
3	14,46	84,34	0,27	0,18	0,75
średnia	14,65	84,19	0,23	0,18	0,75

Fig. 5. Spectrum of element distribution analysis, distribution of test points, percentage distribution of elements in the tested coating on a steel substrate

Conclusions

The aluminum powders used for cold gas spraying allowed to obtain coatings with low porosity. The resulting coating on the 4330 steel substrate met the requirements. No corrosive centres occurred on the coating. The oxygen in the coatings is present from the surrounding atmosphere. However, the coating on the Al 7075 substrate cracked, which could have been caused by the improper preparation of the surface of the layers, contamination of the layers and the time intervals between the application of the individual coating layers. The qualitative analysis of the phase composition of the obtained coatings showed that they are composed of pure aluminum. The obtained coatings have very good anti-corrosion properties.

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