The mechanical properties of AlSi coatings made by PVD technology

Mechaniczne właściwości powłok AlSi wykonanych technologią PVD

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DOI:https://doi.org/10.17814/mechanik.2017.1.15

The mechanical properties (microhardness and scratch test) of AlSi coatings made by PVD magnetron sputtering method from alloys with 7-20%Si were compared. Higher concentration of Si increased deformation resistance of the coating, expressed by depth of scratch. Improved mechanical properties had coatings from alloys modified by TiBAl refiner.
KEYWORDS: protective coatings, PVD coatings, AlSi alloys

Porównano mechaniczne właściwości (mikrotwardość i test rysy) powłok AlSi wykonanych metodą PVD magnetronowego rozpylania stopów o zawartości 7–20% Si. Większe stężenie Si zwiększało opór odkształcania powłok wyrażony głębokością rysy. Lepsze właściwości mechaniczne miały powłoki ze stopów modyfikowanych TiBAl.
SŁOWA KLUCZOWE: powłoki ochronne, powłoki PVD, stopy AlSi

In the production of exhaust systems in the automotive industry, ferritic sheets hot-dip covered with AlSi coatings are often used presently [1]. Al-based protective coatings constitute the main protection against the influence of a corrosive medium at elevated temperature, including exhaust gas [2, 3, 4]. The tendency of Si to crystallizing from liquids in the form large and acute-angled crystals causes the risk of breaking the continuity of coatings to occur during the press forming of parts, as well as during their bonding. This urges the manufacturers to look for technological solutions for the application of coatings on finished products among the PVD techniques.

The application of coatings by the PVD (Physical Vapour Deposition) method involves the deposition of a material, previously brought in a gaseous state, on a substrate. PVD techniques are currently among the most commonly used methods of producing nanocrystalline coatings of unique structural features [5]. To produce homogeneous multicomponent coatings, several discs of different materials are sputtered simultaneously in large vacuum installations. In this study, a single disc of a multi-component material was used. According to literature information, Al and Si show a different tendency to sputtering. It is estimated that aluminium sputters approx. 2 times faster than silicon [6]. Having in mind the different susceptibility of Al i Si to sputtering, as well as the varying thermal expansion of the phases (α_{Al} and Si) [7] already in the coating, the effect of phase refining (by modification with the TiBAl refiner) in the sputtered alloys on the mechanical properties of coating was additionally determined in the study.

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Material and research methodology

AlSi coatings fabricated on the 1.4512 steel substrate in the magnetron sputtering technology were investigated. Sputtering discs were made from AlSi casting alloys with the sub-, peri- and hypereutectoid composition, respectively: AlSi7, AlSi11 and AlSi20. One of the coating series was fabricated from AlSi11 and AlSi20 subjected to modification with the TiBAl refiner during casting with the aim of refining the phases (α_{Al} and Si). The chemical composition of the coatings, as determined on their surface, and coating thicknesses are given in the table.

TABLE. Chemical composition (EDX) and thickness of the test coatings. M – coating of an alloy modified with TiBAl

Coating	Al, %mas.	Si, %mas.	Thickness, mm
AlSi7	92,8	7,2	9,00
AlSi11	87,3	12,7	9,67
AlSi11-M	87,6	12,4	9,45
AlSi20	83,9	16,1	10,80
AlSi20-M	78,9	21,1	10,80

The mechanical properties of the coatings were assessed in the hardness test by the Knopp method on a Future-Tech FV-7 tester under a load of 10G (~98,1 mN), making 3-5 impressions. In addition, the scratch test was performed on a Revetest Xpress CSM Instrument, whereby a 5 mm-long scratch was made with a force ramping from 1N to 15 N.

The microstructures of the obtained coatings were similar in character: silicon crystallites (Si) occurred against a background of the aluminium matrix (α_{Al}). It was observed that on the coating cross-sections the silicon crystallites were arranged preferentially in the forms of chains along the direction perpendicular to the substrate (fig. 1).

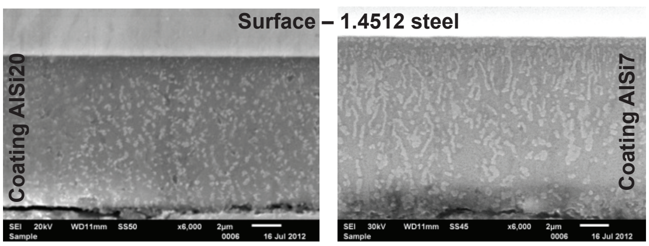

Fig. 1. AlSi7 and AlSi20 coating microstructures on the cross-section (a JEOL 6610LV scanning microscope), etched with 1% HF

In the AlSi7 and AlSi12 coatings, the Si crystals were arranged uniformly over the entire coating thickness. In the AlSi20, in the outer zone, the distribution of Si crystal was non-uniform. It can be supposed that for this reason the Si concentration in this coating, as determined by micro-region analysis (EDX), also deviates from the Si concentration in the sputtered alloy.

Investigation results and discussion

The microhardness of the AlSi7 and AlSi11 alloy coatings was comparable, amounting to approx. 160 HV0.01. The hardness of the AlSi20 alloy coating was much greater, reaching a value of 247 HV0.01. Nevertheless, it should be noted that the determined hardness values of this coating showed a large scatter ($\sigma = 8.5$ μm), much greater than for the remaining coatings.

Sputtering the alloys modified with the TiBAl refiner resulted in a change in the hardness of the coatings made of those alloys. In the case of the AlSi11 coating, a slight increase in hardness up to a value of 178 HV0.01 occurred. In the AlSi20 coating, a similar hardness was obtained, though it was lower by almost 30% compared to that of the unmodified alloy coating (fig. 2).

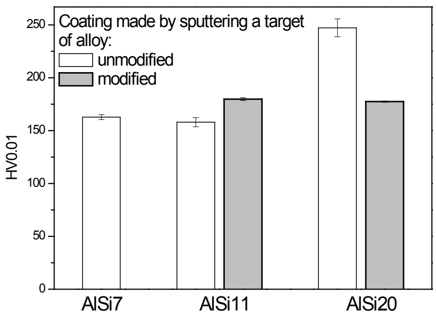

Fig. 2. The microhardness of AlSi coatings

The scratch test results, in the form of a graphical presentation of variations in scratch depth under the load P_d and during retracting indenter displacement R_d, are shown in figure 3*a*. All coatings retained cohesion and adhesion during the test, without any spalling and cracking (fig. 3*b*).

a)

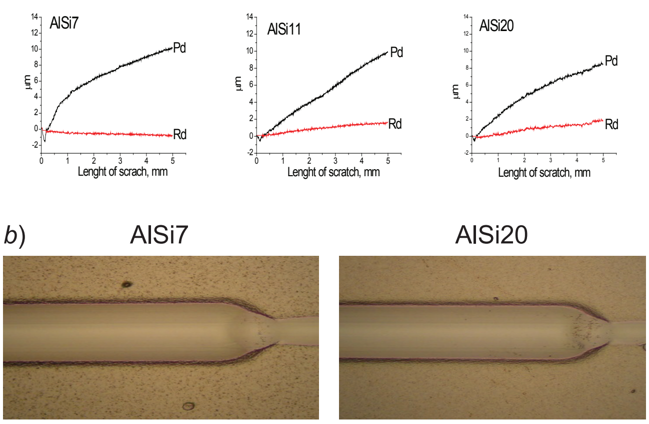

Fig. 3. Variations in scratch depth under loading (*a*); view of the scratches with the maximum depth, Pd (*b*)

The greatest scratch depth (> 10 μm), larger than the coating thickness, was obtained in the AlSi7 alloy coating, while the smallest scratch depth (< 9 μm), and smaller than the coating depth, was obtained in the AlSi20 alloy coating (fig. 4). The scratch depth was, therefore, in correlation with the Si concentration in the coatings.

In the scratch tests, no support for distinguishing the AlSi20 coating was found, as was the case in the hardness tests. It should, therefore, be recognized that the higher hardness value of this coating, burdened also with a large error, reflects a non-uniform arrangement of silicon crystals in its outer zone. This implies that carrying out coating hardness tests as per the requirements of the method, i.e. with an impression depth of up to 0.1 of the coating thickness, may not be representative. Therefore, they were extended in the study by adding the measurement by the scratch method.

The measurements of the scratch depth, Pd, show an advantageous effect of the modification of the AlSi alloys designed for sputtering. Scratches in coatings fabricated from such alloys had a depth smaller by 3 to 6%, respectively, for the AlSi11 and AlSi20 coatings.

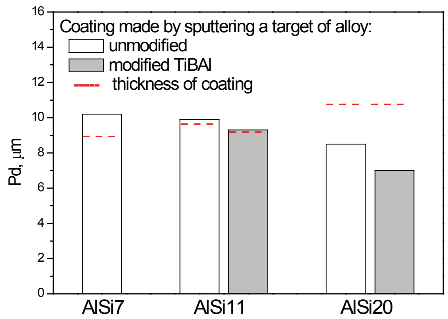

Fig. 4. The depth of scratches in coatings under a load of 15N

Summary

A relationship between the silicon concentration in AlSi alloy PVD coatings and their susceptibility to deformations under loading has been found in the study. The highest susceptibility to deformations, as expressed by the scratch depth, under a load of 15N is exhibited by AlSi7 alloy coatings, while the lowest susceptibility, by AlSi20 alloy coatings.

Coatings fabricated from AlSi alloys modified by the TiBAl refiner are characterized by a hardening as expressed by an increase in HV0.01 hardness by approx. 10%, and a smaller scratch depth Pd by 3÷6%, compared to coatings made from unmodified alloys. The higher mechanical properties of the coatings are due to more uniform sputtering of the alloy with a refined structure.

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