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Evaluation of the Possibility to Improve the Scratch Resistance of the AZ91 Alloy by Applying a Coating

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Abstract

This paper presents the possibility of improving the scratch resistance of the AZ91 magnesium alloy by applying a WCCoCr coating using the Air Plasma Spraying (APS) method. The coating thickness ranged from 140 to 160 μm. Microstructural studies of the AZ91 magnesium alloy were performed. The chemical composition of the WCCoCr powder was investigated. The quality of the bond at the substrate–coating interface was assessed and a microanalysis of the chemical composition of the coating was conducted. The scratch resistance of the AZ91 alloy and the WCCoCr coating was determined. The scratch resistance of the WCCoCr powder-based coating is much higher than the AZ91 alloy, as confirmed by scratch geometry measurements. The scratch width in the coating was almost three times smaller compared to the scratch in the substrate. Observations of the substrate–coating interface in the scratch area indicate no discontinuities. The absence of microcracks and delamination at the transition of the scratch from the substrate to the coating indicates good adhesion. On the basis of the study, it was found that there was great potential to use the WCCoCr powder coating to improve the abrasion resistance of castings made from the AZ91 alloy.

Keywords: AZ91 magnesium alloy, WCCoCr coating, Microstructure, Scratch test

1. Introduction

Magnesium is one of the lightest structural materials. It has a low density, which is 1.74 g/cm^3, good damping properties, as well as high heat dissipation capacity. To increase its strength, magnesium is used with alloying additions, such as: zinc, zirconium, aluminum, manganese, rare earth elements, silver, silicon, thorium, copper, lithium, and yttrium. Magnesium alloys can be divided into groups depending on the content of the main alloying additions: Mg-Al, Mg-Mn, Mg-Zn, and ultra-light Mg-Li alloys. These alloys are characterized by a high strength-to-weight ratio, good machinability, excellent casting properties, and easy recoverability through recycling [1-3].

Magnesium is used in a variety of industries due to its many benefits. The automotive sector uses magnesium alloys mainly to reduce vehicle weight, which brings economic and environmental benefits [4]. Car manufacturers use pressure castings of magnesium alloy mainly for door structural elements, seat frames, steering wheels, dashboards, and gearbox casings [5]. The production of components based on magnesium alloy for the aviation industry is limited to applications for engine parts and drive systems [6]. Magnesium is also used for electronic equipment and power tool components. Good electromagnetic shielding, vibration damping, and the ability to produce portable equipment have resulted in mobile phone cases, laptops, or cameras being made of Mg alloys. Due to its low weight and good biocompatibility, magnesium is used in medicine as an implant material [5,7,8].

High reactivity, low melting point, low abrasive wear resistance, and low corrosion resistance limit the possibility of using magnesium alloys. Authors of the work [9] examined the sliding wear process for the AZ91 magnesium alloy. They analyzed the effect of loads of different values on the surface temperature during its wear. The use of a low-value load meant that the friction surfaces had an equal temperature and a constant wear rate. However, the use of a high-value load resulted in an increase in the temperature of the wear surface and an increase in their wear rate. The authors of the publication [10] compared selected magnesium alloys in terms of friction coefficient values. Alloys AZ31 and AZ61 were tested, for which the values of the friction coefficient were $\mu = 0.296$ and $\mu = 0.326$, respectively. These authors also studied the mechanism of material destruction and wear processes through oxidation.

The constantly growing interest in magnesium alloys results in the need to conduct research on improving the tribological properties of this material. These properties can be improved by using coatings. To properly protect the substrate, the created top layer should be homogeneous and free of porosity. There are many methods of applying coatings. The main techniques for their production are electrochemical, conversion or hydrogen coating, anodizing, and Air Plasma Spraying or Atmospheric Plasma Spraying (APS) [11,12].

Using the APS method of applying in a plasma stream, any material can be used, such as: metal, ceramics, cermet, or polymer. The coating is created from powder carried in a plasma stream to the substrate material in a state of partial or complete melting [13].

The aim of the work was to assess the possibility of improving the scratch resistance of the AZ91 magnesium alloy by applying a coating from WCCoCr powder to the surface of the samples using the plasma spraying method (APS). To assess the quality of the substrate–coating interface, microstructure studies, chemical composition analyses, and scratch resistance tests were performed.

2. Materials and Research Methodology

The material substrate comprised AZ91 magnesium plates with dimensions of 50x50x10 mm. Samples for testing microstructure and scratch resistance were cut from a ready-made alloy provided by a company specializing in the production of foundry alloys. To reveal the microstructure, the samples were etched in nital. Figure 1 presents a sample microstructure of the AZ91 alloy. The α solid solution structure and γ intermetallic phases were observed. The presence of eutectics β (α+γ) was found near the intermetallic phase.

The chemical composition of the alloy is shown in Table 1.

Table 1.
Chemical composition of AZ91 alloy

Content, %wt.			
Al	**Zn**	**Mn**	**Mg**
8.74	0.49	0.22	remainder

The alloy's elemental content complies with the ASTN B93/B93M standard.

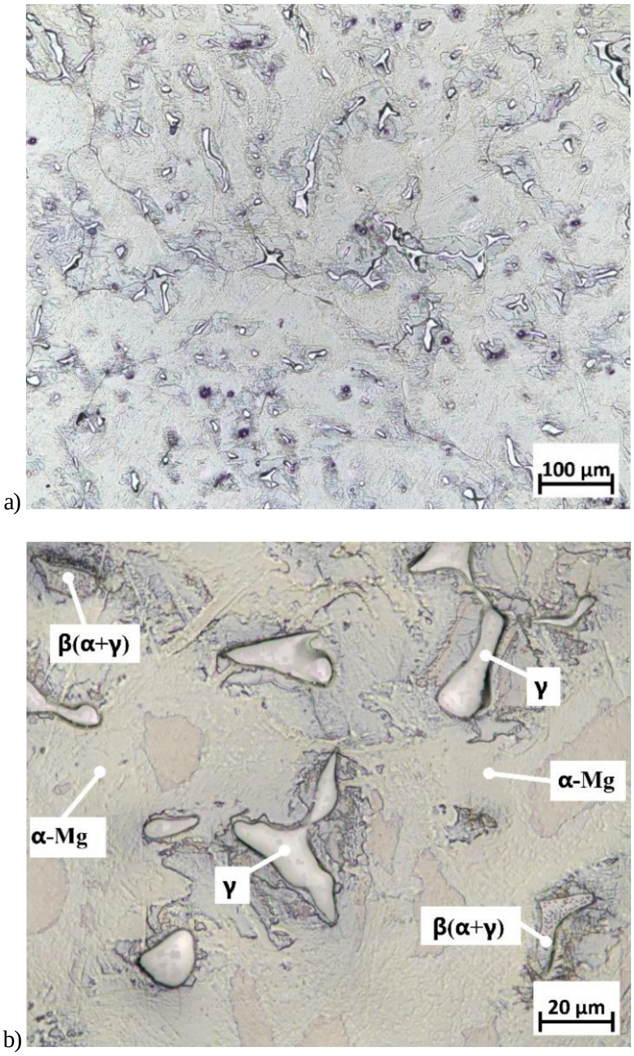
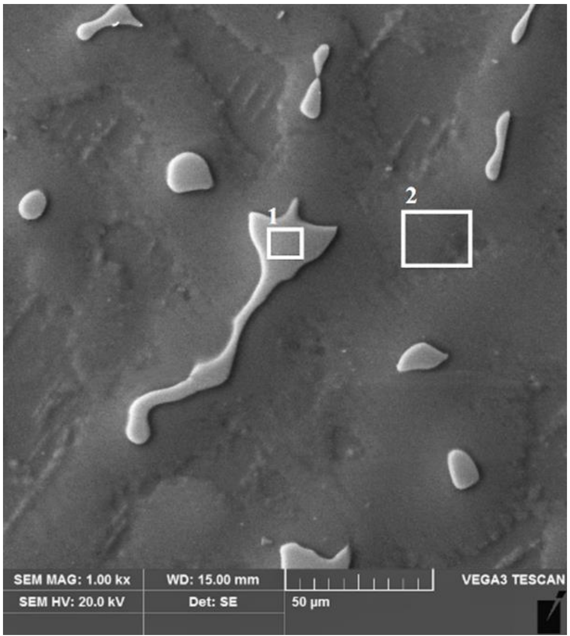


Fig. 1. AZ91 alloy microstructure, magnification 100x (a) and 500x (b)

Figure 2 shows the results of the X-ray microanalysis of the AZ91 alloy's chemical composition. The chemical composition analysis suggests that the matrix is made up of a solid solution of aluminum in magnesium α-Mg. The revealed intermetallic phase can be classified as the γ-Mg17(Al, Zn)12 phase due to its aluminum content.

The coating was produced using WCCoCr powder. Figure 3 shows an image of the powder particles.

Two types of powder particle shapes were observed. The size of spherical-shaped particles ranged from 1.5 – 31 µm, while irregular-shaped particles ranged from 8 – 38 µm. The results of the X-ray microanalysis of the powder particles' chemical composition are shown in Figure 4.



Area	Elemental content, %wt.		
	Mg	**Al**	**Zn**
1	58.13	38.81	3.06
2	94.44	5.12	0.44

Fig. 2. Results of the X-ray microanalysis of the chemical composition of AZ91 alloy

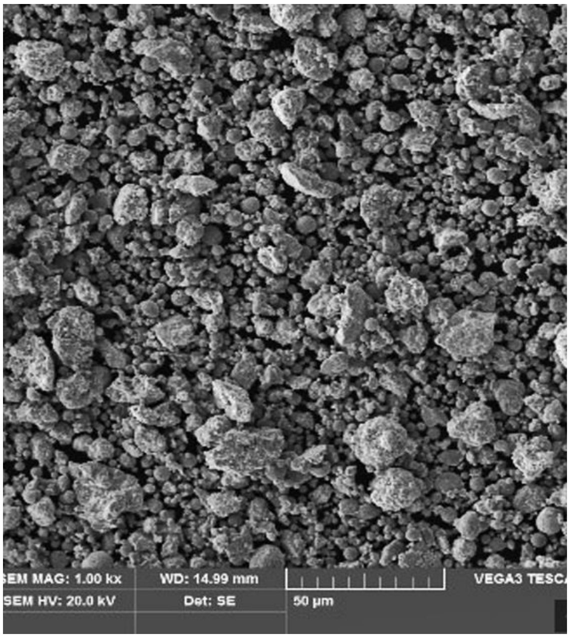
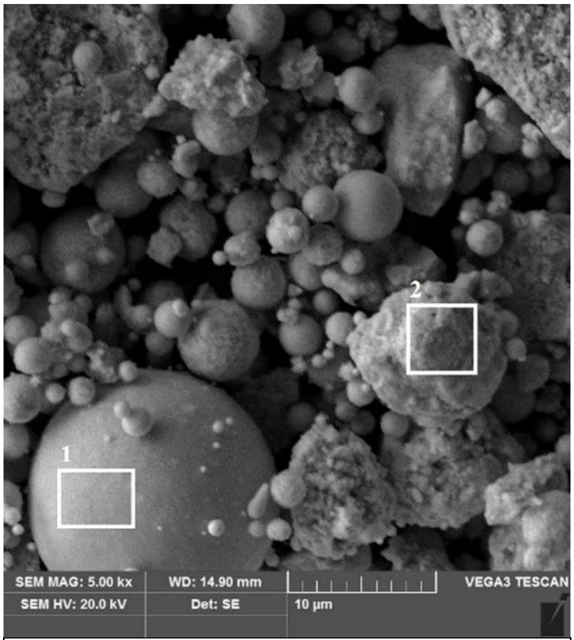


Fig. 3. SEM image of WCCoCr powder

The chemical composition analysis shows that the elemental content in both spherical and irregular particles is at a similar level.



Element, %wt.	Shape of powder particles	
	spherical	**irregular**
W	77.9 – 81.4	72.6 – 83.7
C	6.7 – 10.9	5.4 – 8.5
Co	8.8 – 10.7	7.9 – 13.5
Cr	1.9 – 4.3	1.1 – 3.3

Fig. 4. Analysis of WCCoCr powder particles

The AZ91 alloy sample was adequately prepared before the spraying process began. A device for blast processing was used. The surface was cleaned and treated with an abrasive in a stream of compressed air. This operation was performed to develop the sprayed surface for better adhesion of the coating to the substrate.

The APS process was performed on an automated Sulzer Metco bench. The powder was fed to the torch through a volumetric Twin-120-A/H dispenser.

Preliminary studies were conducted to determine the process parameters. A layer thickness in the range of 140 to 160 μm was used as a criterion for the correctness of the coating. It turned out that in order to obtain a coating of this thickness, it is necessary to use the parameters shown in Table 2.

The microstructure and chemical composition of the coating were investigated using a Tescan Vega 3 scanning microscope equipped with Oxford's Ina x-act X-ray microanalysis attachment.

The scratch resistance analysis – a scratch test was carried out using the Revetest Scratch Tester. A Rockwell C-281 diamond indenter with a tip radius of 200 μm was used for the test. The scratch was made from the substrate to the coating. The scratch length was 1 mm. The load force value was constant and was 5 N. An indenter movement speed of 5 mm/min was used. Scratch tests were supplemented with surface scratch observation results using a scanning microscope.

Table 2.
Process parameters for spraying the WCCoCr coating

Process parameter	Value
Torch feed rate	160 mm/s
Amperage	630 A
Gas output	Ar – 60 l/min
	H – 1 l/min
Amount of powder fed	Dispenser disc – 0.45 rpm
	Mixer – 90%
Distance of the torch from the part to be sprayed	100 mm
Carrier gas for powder	Ar – 3 l/min
Type of refrigerant gas	Air, pressure 6 bar
Number of passes	20

3. Research Results and Their Analysis

The microstructure of the WCCoCr coating applied to the AZ91 magnesium alloy substrate is shown in Figure 5 and Figure 6.

Observations of the substrate–coating interface indicate no discontinuities, suggesting good adhesion of the coating to the substrate.

Figure 7 presents the results of X-ray analysis of the chemical composition of coating areas with different colors. Despite differences in coloring of the analyzed areas of the coating, the contents of chromium, cobalt, and magnesium are at a similar level.

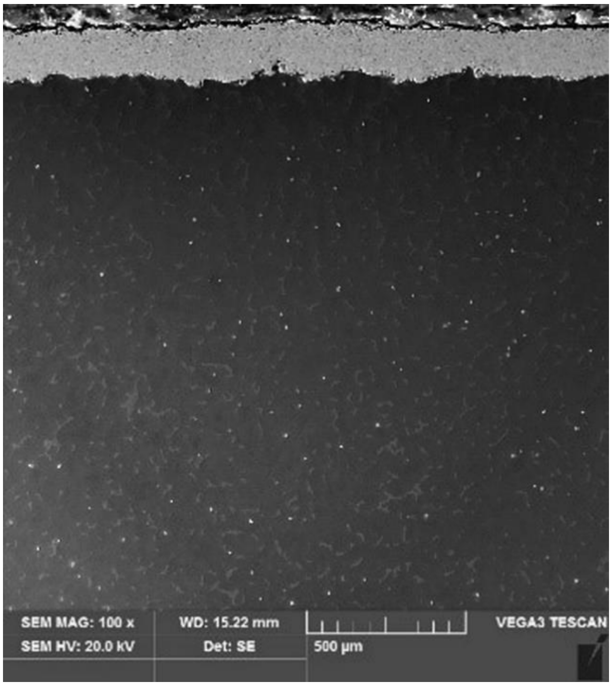


Fig. 5. View of the microstructure of the WCCoCr powder coating on AZ91 substrate, magnification 100x

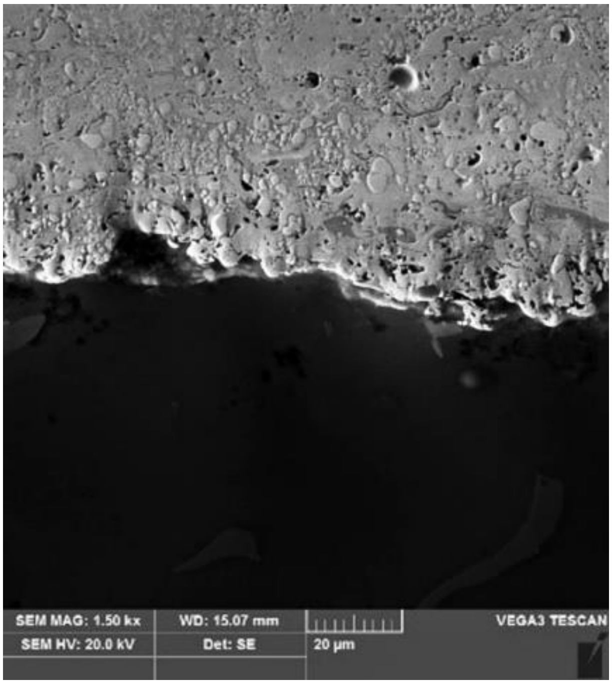
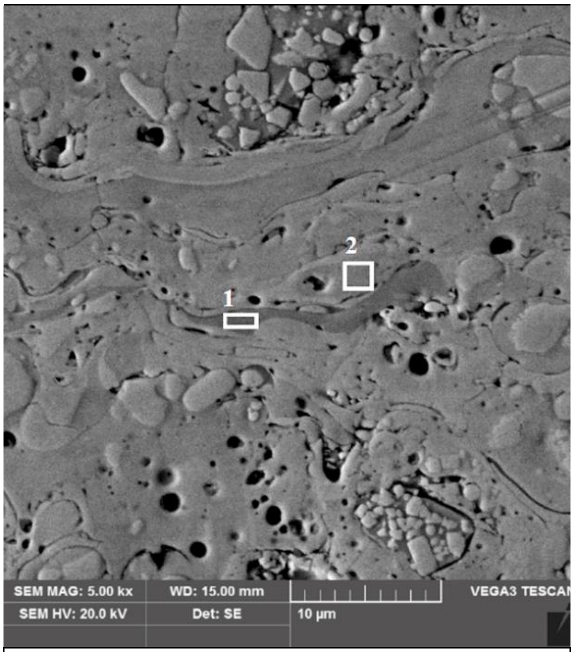


Fig. 6. View of the microstructure of the WCCoCr powder coating on AZ91 substrate, magnification 1500x



Point	Elemental content, %wt.			
	C	Cr	Co	W
1	2.73	0.46	10.90	85.91
2	5.42	0.68	10.91	82.99

Fig. 7. Microstructure of the WCCoCr coating and results of chemical composition analysis

Figure 8 and table 3 shows the scratch test results. During the formation of the scratch, the depth of penetration, the value of the coefficient of friction, the frictional force and the contact force were measured, as well as the acoustic emission signal.

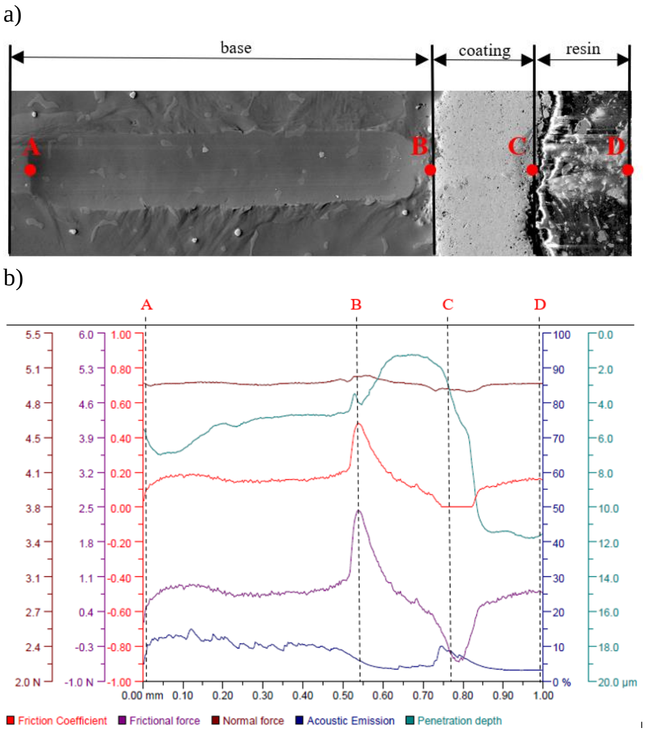


Fig. 8. View of the scratch surface (a) and scratch test results (b)

Table 3.
Scratch test results

Parameters	Material	
	AZ 91	Coating WCCoCr
Penetration depth, μm	3.8 – 6.9	1.2 – 4.0
Penetration width, μm	104 - 107	35 - 38
Friction Coefficient	0.05 – 0.4	0 – 0.48
Frictional force, N	0.5 – 1.8	-6 – 2.5
Acoustic Emission, %	3.7 - 12	3.5 - 10

The obtained results indicate significantly lower values of the depth and width of the scratch made on the WCCoCr coating compared to the AZ91 alloy. The greater scratch resistance of WCCoCr coating comes from presence of hard tungsten and chromium carbides. The values of the friction force and friction coefficient for cracks made on the AZ91 alloy and in the WCCoCr coating are at a similar level. However, clear changes were observed in the analyzed parameters at the substrate-coating transition boundary.

The view of the scratch surface along with measurements of the scratch width in the substrate and the coating are presented in Figure 9.

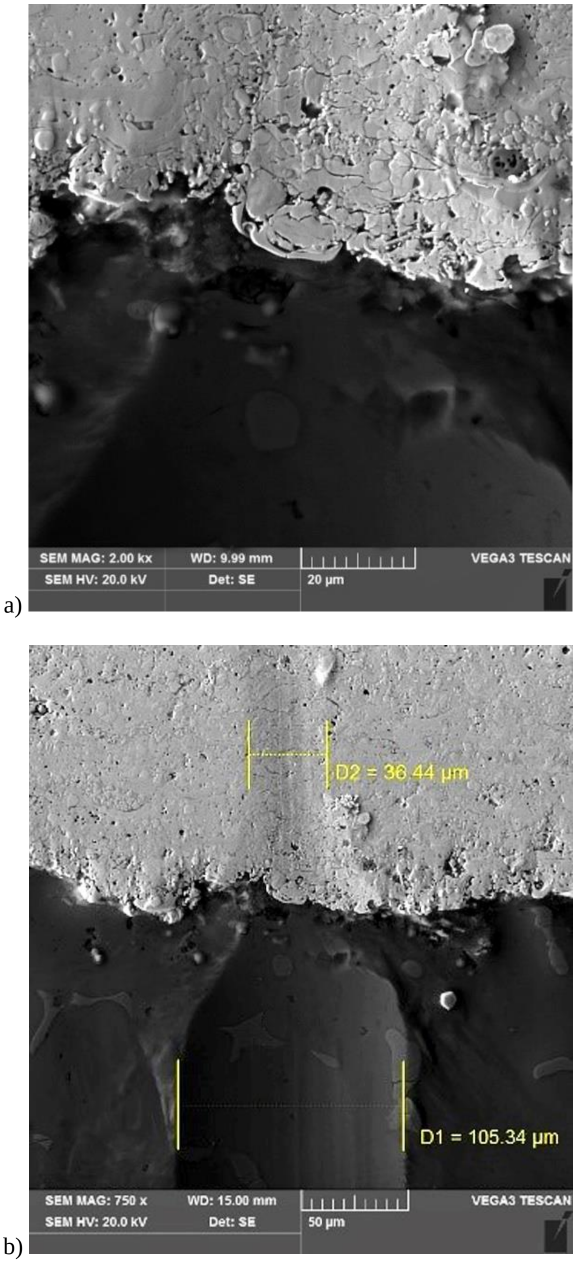


Fig. 9. View of the scratch surface at the substrate–coating interface (a) and scratch width measurement (b)

Observations of the substrate–coating interface in the scratch area indicate no discontinuities (Figure 8a). The absence of microcracks and delamination at the transition of the scratch from the substrate to the coating indicates good adhesion.

The scratch test results obtained indicate that the coating material is significantly less susceptible to scratching. The depth of scratching in the AZ91 alloy substrate ranged from 6.8 – 4.2 µm, while in the coating, it was much smaller and ranged from 3.8 – 1.3 µm. The scratch width in the substrate was about 105 µm, while in the coating, it was about 36 µm.

4. Conclusions

The scratch resistance of the WCCoCr powder-based coating is much higher than the AZ91 alloy, as confirmed by scratch geometry measurements. The scratch width in the coating was almost three times smaller compared to the scratch in the substrate.

On the basis of the study, it was found that there was great potential to use the WCCoCr powder coating to improve the abrasion resistance of castings made from the AZ91 alloy.

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