Ghufran J. Matrood
Niveen J. Abdulkader
Nahedh M. Ali

University of Technology - IRAQ

Determination of Electrical Conductivity of Aluminum Nano Films prepared by Flame Thermal Spray

This study measured the electrical conductivity of the Al coating layer deposited on acrylonitrile butadiene styrene (ABS) by flame thermal spraying. The results showed that the electrical conductivity of aluminum coating on the ABS polymer substrate were good but lower than that in bulk aluminum, with values of 1.68×10^4 – 2.17×10^4 $\Omega^{-1}.cm^{-1}$. The scanning electron microscopy (SEM) also showed good adhesion force between the Al coating layer and the surface of the polymeric substrate; the results of the x-ray diffraction (XRD) showed no oxidation. The contact angle for the ABS substrate was 36.442°, meaning that the ABS surface is hydrophilic and has good surface energy and adhesiveness.

Keywords: Thermal spraying; Electrical conductivity; Metallization; Polymers
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1. Introduction

Nanotechnology is considered to have a significant influence on nearly every aspect of human life. Nanotechnology possesses the capacity to profoundly impact many domains, including physical sciences, biotechnology, energy, communication technology, social psychology, manufacturing, cognitive sciences, catalysis, computational sciences, and transportation. It has the ability to revolutionize the future by increasing the durability and reactivity of existing materials [1,2].

Thermal spraying is a process where molten, or partially molten materials are applied to a surface to create a coating. The coating substance is applied with a high-velocity spray. When the coating particles come into contact with the surface of the substrate, they can experience permanent deformation, resulting in the creation of a coating layer. The coating material can be employed in either a powder or a wire form. Oxygen and acetylene are the usual gases used for generating heat. The flare induces rapid melting of the coating material, which is then violently ejected onto the substrate's surface [3].

Metallization refers to the process of depositing metal layers onto the polymeric substrate using thermal spraying. This technique is accomplished through the adhesion of the sprayed metal to the polymeric surface. Thermal spraying process factors, such as particle speed and temperature, influence the deposited plates. The deposited layer is also affected by the substrate's surface roughness and the angle between the substrate and the particle line [4,5].

Aluminum has a density of 2.7 g/cm^3, which is approximately one-third of the densities of steel and cast iron [6]. Aluminum alloys typically consist of silicon, copper, magnesium, zinc, and several additional alloying elements. They possess the benefits of being lightweight, exhibiting good electrical and thermal conductivities, and demonstrating exceptional mechanical qualities [7,8].

Acrylonitrile butadiene styrene (ABS) is a thermoplastic material that has several applications in engineering because to its beneficial qualities. These properties include chemical resistance, light weight, strong mechanical capabilities, and ease of processing [9]. Materials with thermal and electrical conductivities, corrosion resistance, and light weight can be obtained by coating a commercially available polymer with a thin layer of aluminum [10]. Voyer et al. [11,12] noted that polyester fabrics became electrically conductive after depositing a layer of aluminum on them by flame spraying, thus obtaining a coating layer with a thickness of 75-100 µm and an electrical resistance of about 0.002 Ω.cm because the aluminum coating did not affect the elasticity of the polyester fabric. Huonnic et al. [13] measured the electrical resistance of flame-sprayed glass and basalt tubes after a layer of aluminum coating was deposited on the surface, which was found to be 69×10^7 and 89×10^7 Ω.cm, respectively. Two flame sprayers were used to produce a uniform metal layer with electrical properties on a polymeric substrate. It was noted that the electrical resistance values of the coated materials were higher than that of annealed aluminum alloy. Affi et al. [14] analyzed the electrical resistance of Al coatings applied by cold and plasma spraying methods onto carbon-fiber-reinforced epoxy substrates. The resistance values of the aluminum deposits that were sprayed with plasma were significantly higher than those of the aluminum coatings that were sprayed with cold. This could be attributed to the increased oxidation of the sprayed particles at higher temperatures of the carrier gas.

The three significant motivations are behind the utilization of metallized polymer in the production of electronic devices is the reduction of costs, decrease of weight, and enhancement of electrical conductivity.

The objective of this research is to modify ABS surface with a metallic coating to enhance electrical conductivity for electronic applications.

2. Experimental Work

Acrylonitrile butadiene styrene (ABS) with a dimension of 2×2 cm^2 was used as a substrate material, and 99.9% pure aluminium powder with a diameter of 61.8 nm was used as a coating material. The chemical composition of Al is shown in table (1).

Before spraying, the substrates were prepared for the coating procedure by cleaning them with NaOH and subsequently roughening them using sandpaper to improve the surface roughness. This step was performed to enhance the coating's ability to adhere to the substrate. Finally, a layer of aluminium coating was applied.

Table (1) Chemical Composition of Pure Al

Element	Ti %	Zn %	Cu %	Fe %	Mn %	Si %	V %	Mg %	Al %
Chemical Composition	0.024	0.033	0.026	0.15	0.045	0.052	0.008	0.028	Balance

The coating method utilised the thermal spraying approach, employing an oxyacetylene thermal spraying device on a two-dimensional table. The table was outfitted with spherical screws and a motor that facilitated the seamless movement of the spraying device in both right and left directions. The operational specimen was placed on a flat surface in front of the spraying apparatus. The screw sample fixture was equipped with a stepper motor, which allowed it to move in a spherical manner. The given sample fixture featured a spherical screw mechanism equipped with a motor that enabled vertical movement in both upward and downward directions [15]. The O_2 pressure was 0.5 bar, while the C_2H_2 pressure was 1 bar. Figure (1) and table (2) displays the thermal spraying device and the spraying parameters, respectively.

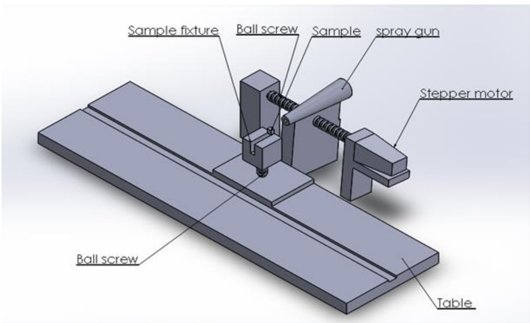


Fig. (1) Thermally spray device

Table (2) Process parameters and their levels

Parameters	Level 1	Level 2	Level 3
Distance mm	150	200	250
Powder feeding gl/min	15	30	45
Spray velocity m/min	100	200	300
Delay time min	4	6	8

3. Results and Discussion

Figure (2) shows the peaks obtained from the x-ray diffraction (XRD) analysis of the aluminum layer on a polymer substrate, and the apparent peaks seem to be very similar to those found in a standard sample. It seems that the intensity of the peaks may vary at angles of 38.36°, 44.67°, 65.12°, and 78.20°. The strong peaks with a narrow base give the impression that the crystal structure of the coating is regular, and the low peaks mean that the coating has a random or irregular structure.

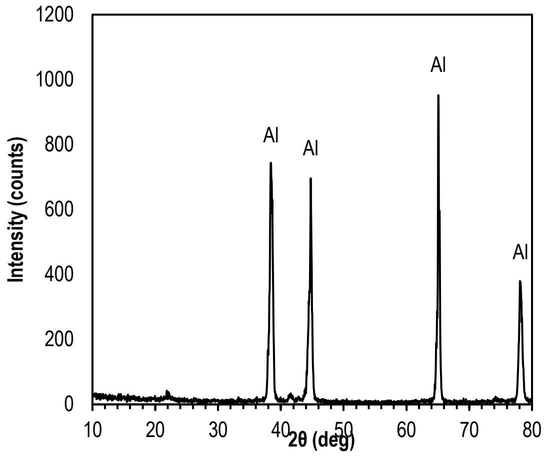
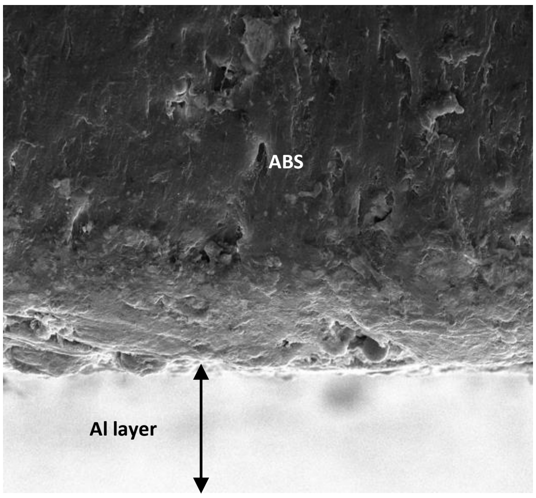


Fig. (2) XRD pattern for Al coating prepared in this work

The SEM of the coated samples was carried out using Inspect S50 SEM instrument to determine the coated layer and measure their thickness as well as the coating-substrate interface. Figure (3) shows the adhesion between the ABS polymer and the Al coating layer. The coating layer had a thickness of approximately 74.35 µm.



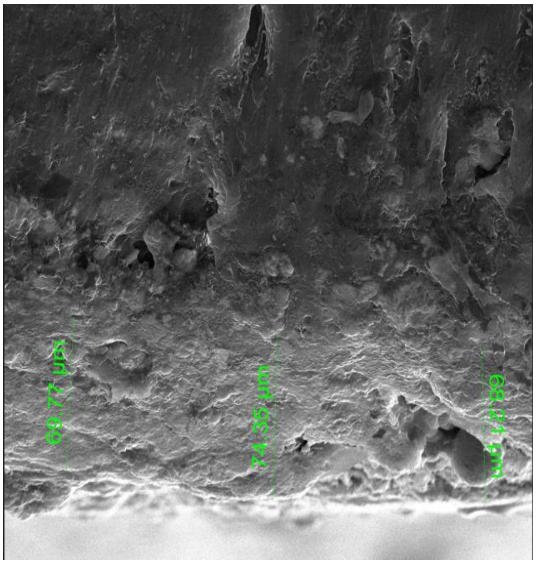


Fig. (3) SEM images showing the interface between polymer substrate and metallic coating

The contact angle is the angle at which the liquid–solid and liquid–vapour interfaces intersect [16]. As shown in Fig. (4), the contact angle test showed that the surface of ABS has a contact angle of 36.422°, which suggests that the surface is hydrophilic and thus, ABS has good wettability and adhesiveness.

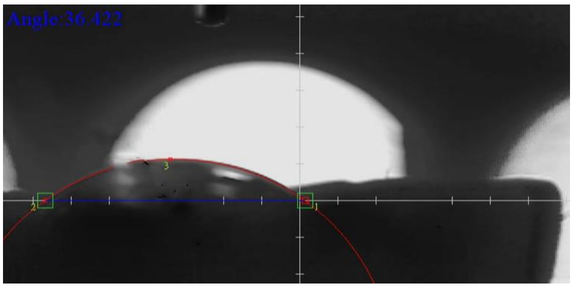


Fig. (4) The contact angle for ABS

Scratch testing is the predominant and preferred method for evaluating the adhesive strength of a coating-substrate system [17-19]. Taguchi orthogonal arrays are utilized to determine the effects that the values of the thermal spraying parameters have on the adhesion strength between the aluminum coating and the ABS substrate. The best adhesion between ABS polymer and Al coating can be obtained if the distance between the gun spray and substrate is 200mm, the powder feeding is 45 gL/min, the velocity of spray is 100 m/min, and the delay time is 6min as shown in table (3).

The electrical conductivity of the coated layer has been measured using an LCR-821 meter. Figure (5) shows that the electrical conductivity of the Al layer is significantly lower than that of bulk aluminum. This is because the nano-coating layer increased the resistance values due to an increase in grain boundaries. The electrical conductivity value of bulk aluminum was $3.77\times10^{7}\ \Omega^{-1}.m^{-1}$.

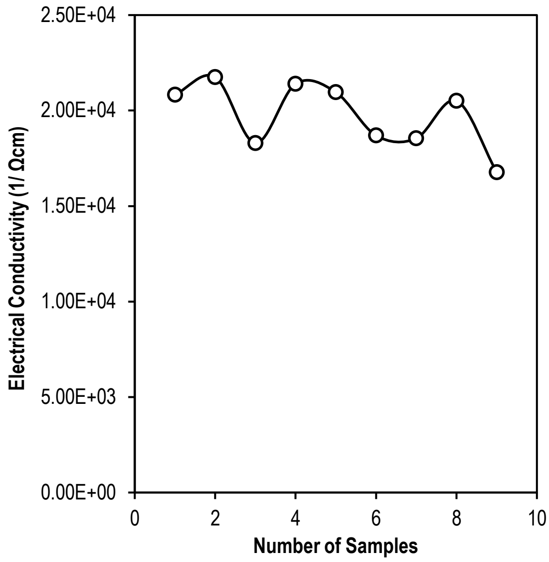


Fig. (5) Electrical conductivity of Al coating layer

4. Conclusion

In this study, aluminum coating layers were deposited on polymer substrates by flame thermal pyrolysis. It was found that the electrical conductivity of these layers are good but lower than the electrical conductivity of bulk aluminum. This is due to the fact that the coating deposited on the polymeric substrate is nano-sized, thus forming many crystalline boundaries. In addition, due to an increase in grain boundaries in the Al layer, the electrical conductivity decreased. The characterization shows that there is no oxidation on the coating layer. The contact angle was 36.224°, suggesting that the surface of ABS is hydrophilic and thus, ABS has good wettability and adhesiveness.

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Table ()3 Taguchi orthogonal array results

No. of samples	Distance (mm)	Powder feeding (g/min)	Spray velocity (m/min)	Delay time (min)	Trial 1	Trial 2	Trial 3	Mean	S/N ratio
1	150	15	100	4	36.90	36.96	36.97	36.9433	31.35
2	150	30	200	6	37.65	37.66	37.67	37.6600	31.52
3	150	45	300	8	38.34	38.37	38.36	38.3567	31.68
4	200	15	200	8	38.41	38.44	38.42	38.4233	31.70
5	200	30	300	4	38.89	38.87	38.87	38.8767	31.80
6	200	45	100	6	43.99	43.95	43.97	43.9700	32.86
7	250	15	300	6	36.73	36.72	36.77	36.7400	31.30
8	250	30	100	8	41.99	42.21	42.22	42.1400	32.50
9	250	45	200	4	43.67	43.70	43.71	43.6933	32.81

Where Trial 1, Trial 2, and Trial 3 are adhesion forces (N)