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Physical Vapour Deposition Method Based Microstructure Analysis of TiN Coated Surfaces in Aluminum Alloy 2024 Grade

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ABSTRACT

The Aluminium Alloy 2024 grade tends to corrode the surface of the material, because it having copper content, it will undergo severe corrosion. Normally these types of Aluminium grade are applied in the building of the body of the aircraft. The main drawback of this material is after the painting, it has to be frequently painted to decrease the corrosion, for those aerospace industries have to spend more amounts for the painting. In this work, we concentrated to get the better strength of Aluminium alloy 2024 grade by reducing the corrosion. The face of the AA2024 is layered with Titanium Nitride (TiN) at ~1.465μm thickness. This coating is prepared by the PVD method, and after the coating process, the specimen is tested using the X-ray Spectroscopy and SEM analysis for surface finish and the hardness test using the Micro hardness test.

KEYWORDS: *Titanium Nitride (TiN), Aluminium Alloy 2024, Physical Vapour Deposition (PVD), Scanning Electron Microscope (SEM)*

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I. INTRODUCTION

In the Aerospace industry, lightweight materials have a major impact on the construction of Aeroplanes; these materials have the properties of more hardness and also a reduction in corrosion properties like Aluminium Alloy 2021 grade materials. These materials having a copper content, and this leads to severe corrosion, while it contacts with oxygen and water. For that, the majority of the Aeroplanes companies paints the materials to withstand the strength and hardness of the materials to increase the lifetime of the print quality. This leads to an increase in the maintenance cost and also it takes frequent maintenance to keep the surface of the materials. The commonly used Aluminium alloy has the attribute of not being able to tolerate high-temperature resistance while also having a low wear resistance. Aluminium alloy 2024 is available in both the forms of plates and in the forms of the sheet; the plates are used in the application of the fuselage structures, whereas the sheets are used in the forms of fuselage skins. In this study we use Titanium Nitride (TiN) as a coating the surfaces of the Aluminium Alloy 2024, the TiN will be the hard materials in the metal family and it applied for the coatings with the less than 5μm.

Most researchers are focused on plasma nitriding a Titanium coating onto the AA2024 to boost its wear resistance. By employing magnetron sputtering, nano-sized titanium particles are coated on the surface of the Aluminium alloy 2024 grade, and then the same is plasma nitrate for eight hours at 300C interval starting from 400^0C to 490^0C and in a gas having a mixture of 40%&60% of N_2 and H_2. As compared to uncoated material, the wear rate is reduced by 56 per cent after this treatment [1]. Some of them are using the Plasma-enhanced chemical vapour deposition method on AA 2024. In this method they using the two different gasses at the ratio of 1:1, i.e. 50% oxygen and 50% hexamethyldisiloxane, plasma is ignited using the radio frequency at 13.56MHz. The power was varying from 10 W to 80W in the 6 different sets of experiments. Salt spray method & electrochemical impedance spectroscopy will be used to assess corrosion resistance[2]. Based on the several researcher methodologies handling the AA 2024 with TiN, we adopted the surface coating using the Physical Vapour Deposition Method (PVDM).

II. Materials and Their Composition

For this study, we use the main materials as the Aluminium Alloy 2024 Grade and the Titanium Nitride Powder. The detailed properties of the Aluminium Alloy 2024 grade are shown in Table 1, and Table.2 describes the detailed properties of the Titanium Nitride.

Table.1 Property of Aluminium Alloy 2024 (AA 2024)

Physical Properties	
Properties	AA 2024
Density	2.78 g/cc
Mechanical Properties	
Tensile Strength	483 MPa
Yield Strength	345 MPa
Modulus of Elasticity	73.1 GPa
Thermal Properties	
Coefficient of Thermal Expansion	23.2 µm/m-°C
Thermal Conductivity	121 W/m-K
Chemical Composition	
Silicon	0.5%
Iron	0.5%
Copper	3.8% - 4.9%
Manganese	0.5% - 0.6%
Magnesium	1.2% - 1.8%
Chromium	0.1%
Zinc	0.25%
Titanium	0.15%

Table.2 Properties of Titanium Nitride

Physical Properties	
Properties	TiN
Density	5.21 g/cm3
Mechanical Properties	
Tensile Strength	240 MPa
Modulus of Elasticity	251 GPa
Shear Modulus	15.6 GPa
Thermal Properties	
Coefficient of Thermal Expansion	9.35×10^{-6} K–1
Thermal Conductivity	29 W/m-K
Melting point	2947 °C
Chemical Composition	
Titanium	77.5%
Nitrogen	22.6%

III. Preparation of the Substrate Material

For this study, we use the basic material as AA2024 grade in the form of a square plate having a thickness of 4mm. After the primary cleaning process carried on the plate, the plate will be cut for the required dimensions. For that the AA2024 grade is cut in the dimensions of 20 x 20 cm using the Wire cut EDM, specification and the picture of the EDM is mentioned in Table.3 and Fig.1.

Fig.1 Wire-Cut EDM

Fig.2 Surface Grinding Machine

Table.3. Specification of Wire cut EDM

Parameters	Range
Maximum Cutting speed	160mm²/min
Surface Finish	0.8 µ
Taper	± 30°/ 50 MME
Table size	445 X 655 mm

After the cutting process, the surface is to be grinding for 0.25 mm using the surface grinding machine, specification and the picture of the surface grinding machine is mentioned in Table.4 and Fig.2.The prepared material is shown in Fig.3.

Table.4. Specification of Surface Grinding Machine

Parameters	Range
Maximum Grinding Dia.	150 mm
Max. Grinding Length	450 mm
Spindle Speed	2800 RPM
Motor Power	1 HP

Fig.3 shows that the prepared substrate of the Aluminium alloy 2024 after all the preparation. Simultaneously, Titanium Nitrides (TiN) is used for this study is in the form of a Powder state, for that Titanium Nitrides (TiN) is to be filtered using Nano filter, from which the above 0.70 µm are filtered as shown in Fig. 4

Fig. 3 Prepared Substrate Material

Fig. 4 Titanium Nitride Powder at 0.70 µm

IV. Experimental Procedure

The prepared substrate material is placed in the workpiece holder and place inside the sputtering machine. The sputtering process is the Physical Vapour Deposition Method, in which the TiN is coated in the Aluminium Alloy 2024 at the thickness of ~1.465µm, and the sputtering machine is shown in Fig.5. Initially, the process is started by using Argon gas. The Argon gas is used to eject at the rate of flow 1.5 mL/min to the Titanium Nitride atoms to coat over the AA2024 for a while. After the air cooling, coating thickness is measure using the coating thickness gauge. This instrument is used to measure up to 1500µm. The finished substrate material after TiN coated is shown in Fig.6. The complete procedure for the TiN coating in the AA 2024 is shown in Fig.7.

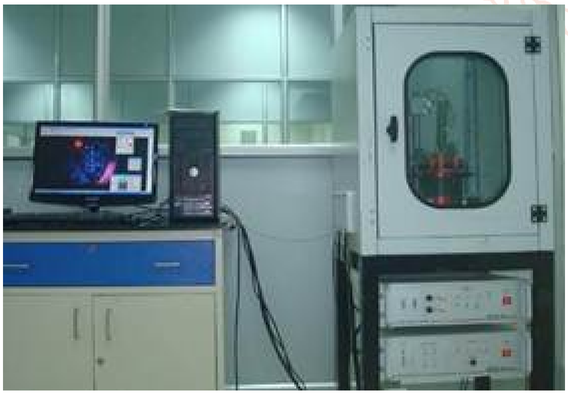

Fig. 5 Sputtering Processing Machine

Fig.6 TiN Coated AA2024

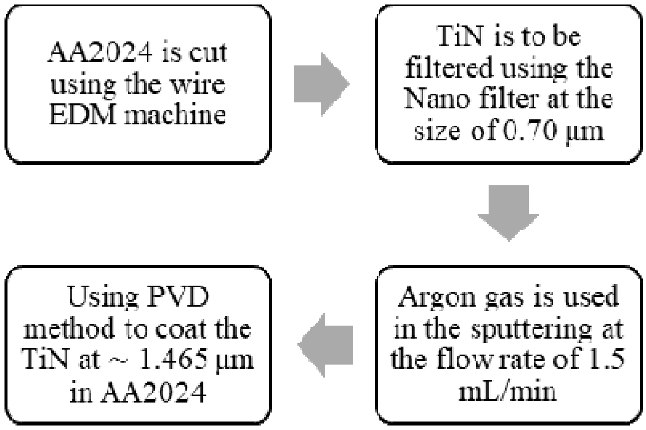

Fig. 7 Procedure for the TiN coating in the AA 2024

V. Testing Process

In this study, there are 3 different testing procedures were studied for the substrate material that will come on the predefined thickness and the surface finish. They are:

A. Coating Thickness:

Used to measure the thickness of the TiN layer in the AA2024. For that 5 samples were taken on each substrate material, and the average thickness is considered for the coating thickness. The instrument used is the Elcometer 456 Coating Thickness Gauge.

B. X-Ray Diffraction Studies (XRD):

This testing helps measure the different phases presented in the TiN coatings. This process was done using the Ni-based Filter Cu-Kα radiation in a Philips X-ray diffractometer. The characteristic d-spacing of all possible values are taken from JCPDS cards and were compared with d-values obtained from XRD patterns to identify the various X-ray peaks obtained.

C. Scanning Electron Microscopic Studies (SEM):

TiN coated AA2024 and the powders were studied under scanning electron microscope mostly using secondary electron imaging. The surface, as well as the interface morphology of all coatings, was observed under the microscope. The detailed procedure for preparing the specimen for the SEM studies is shown in Fig. 8.

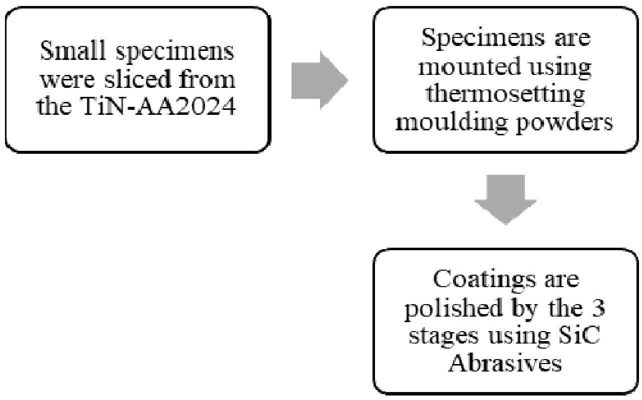

Fig. 8 Procedure for preparing the specimen for SEM

VI. Results and Conclusion

A. SEM Analysis:

Fig. 9 shows the surface of the TiN coating in the Aluminium Alloy 2024. The surface finish of the coating is smooth and the thickness we get is 1.465 µm. The magnitude will be 1.00 KX and EHT will be 10.00 KV and WD will be 10.4 mm, and the signal A = SE2. The coating is viewed in the microscopic at 20µm. After the SEM analysis, using the Electron is diffracted on the target material to view the surface of the coating as shown in Fig.10.

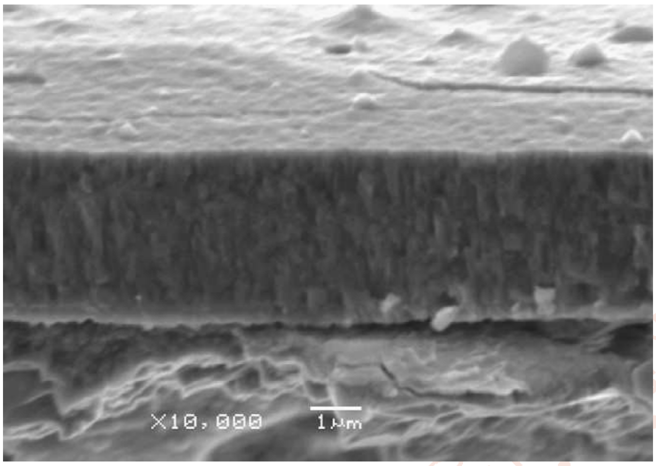

Fig.9. The cross-section and the surface of the TiN coating, SEM

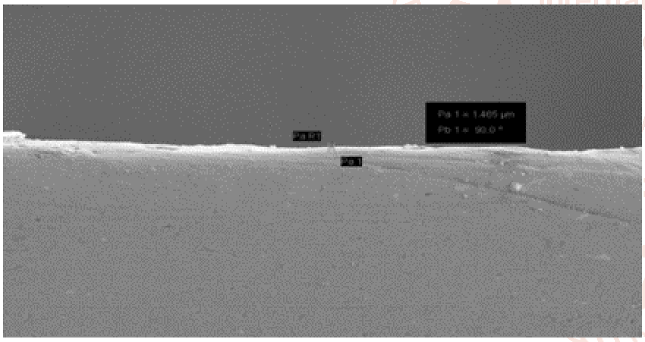

Fig.10 Surface of material through SEM

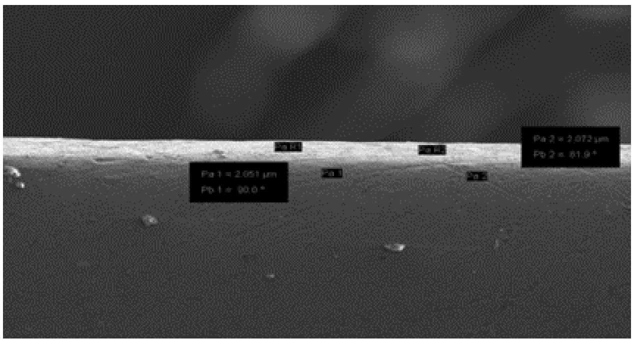

Fig.11.Electron diffraction on the target material

This surface of the TiN coating material is shown in Fig. 11 using the microscopic view. This will help the TiN is packed with the AA2024 without the air bubbles in between the molecules of TiN.

B. Hardness Test:

In this testing method, the use of a diamond indenter with a particular shape is used to make an impression called as test load or applied force, which can be at 1-1000gf, on the material under testing. And the diameter of the indentations test involves 50mm and 60mm, which are roughly equivalent to 2gf. This force can produce an indentation of around 50µm. Fig.12 shows that the different loading conditions at 1µm, 1.46 µm, 2 µm, 2.2 µm. Because of its specificity, this type of testing is applicable in cases where there is need to watch for hardness changes on a microscopic level.

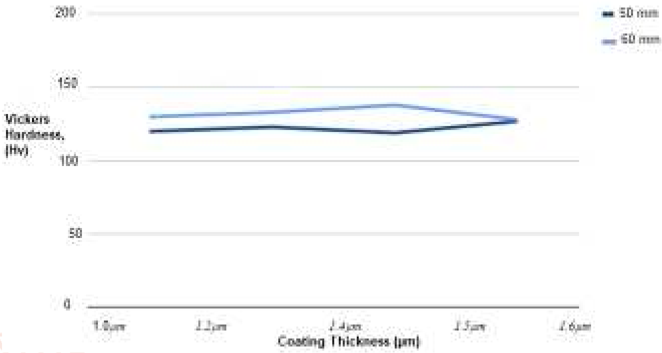

Fig.12 Hardness Test after coating

C. XRD Analysis:

From this Fig.14, we obtained that the Titanium nitride was finely coated over the substrate Aluminium and the characteristics of the substrate for various thicknesses was studied, examined and analyzed over the period of time and results were obtained.

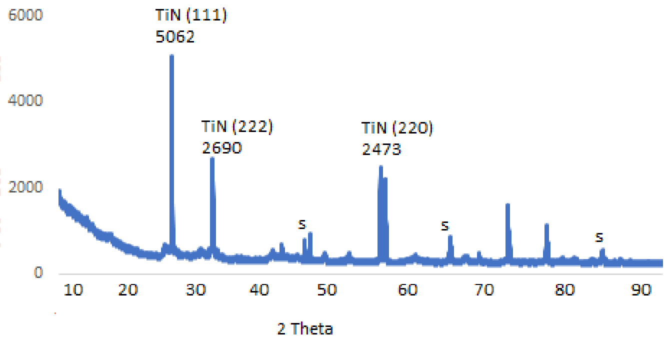

Fig.14. XRD Analysis

We conclude this study as a substrate was designed for the sputtering process in which Titanium Nitride was coated over Aluminium 2024 alloy by physical vapour deposition of gas. The resulting prototype was then tested to get the appropriate results in different loading conditions various types of tests were taken to get the best result of the substrate for which it was developed. From that, we conclude that Titanium Nitride coated Aluminium 2024 alloy possesses excellent result compared to normal Aluminium alloy.

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