Al-Khwarizmi Engineering Journal
ISSN (printed): 1818 – 1171, ISSN (online): 2312 – 0789
Vol. 20, No. 4, December (2024), pp. 89-98

Al-Khwarizmi Engineering Journal

Enhancing the Surface Mechanical Properties of AL2618 Alloy Turbochargers Using a PLD Device with AI_2O_3

Sarah S. Faraj[1], Nabil H. Hadi[2*]

[1] *Department of Mechanical Engineering, University of Baghdad, Baghdad, Iraq*
[2] *Departments of Aeronautical Engineering, University of Baghdad, Baghdad, Iraq*
*Corresponding Author' s Email: Dr.Nabil.Hassan@coeng.uobaghdad.edu.iq

(Received 29 April 2024; Revised 18 June 2024; Accepted 28 July 2024; Published 1 December 2024)
https://doi.org/10.22153/kej.2024.07.004

Abstract

Pulsed laser deposition (PLD) has become a widely used technology for fabricating multicomponent thin films. In this research, nanomaterial Alfa-Al_2O_3 with a particle size of 30 ± 5 nm was deposited on the surface of AL-2618 alloy turbine blades. The microstructure, phase composition and the effects of a coating made from Alfa-Al_2O_3 nanomaterial were studied. PLD was employed to improve the mechanical performance of the aluminium alloy (AL-2618) used in turbocharger blades, primarily to reduce corrosion and erosion. To ensure high hardness and extended fatigue life, a 10 µm layer of aluminium dioxide was deposited on the surface of the aluminium alloy using PLD. The mechanical properties of the blade improved, as shown by hardness tests conducted on the samples. An energy-dispersive X-ray spectroscopy test was conducted before and after deposition. After depositing a nanolayer of Al_2O_3, the mechanical properties were enhanced. The hardness of the samples increased from 685 HLD to 781 HLD, and corrosion and erosion were reduced. The atomic percentage of oxygen deposited on the blade surface ranged from 0.6% to 0.8%, and the surface roughness (x) decreased from 49.5 µm to 22.8 µm because of the nanolayer applied via PLD.

Keywords: *Turbocharger Blade; Surface Improvement; Nanomaterial (Alfa- Al2O3), Corrosion; Erosion; PLD*

1. Introduction

Since the early 20th century, precipitates have been used to reinforce various alloys. In recent decades, extensive research has focused on alloys with nanostructured (NS) or ultrafine-grain (UFG) structures, both of which share the challenge of poor ductility [1]. The precipitation behaviour in NS or UFG alloys differs from that in their conventional coarse-grained counterparts. However, adding precipitates has been proven to be a viable technique for resolving the strength–ductility tradeoff. A review of precipitation's scientific discovery in the last 20 years in NS or UFG alloys is presented in this article. The study covered the growth and formation mechanism of precipitates, their interactions with dislocations, grain boundaries or solid solutes and the resulting mechanical behaviour [1]. Pulsed laser deposition (PLD) is the most common physical method for thin films, obtaining a coating with qualitative specifications and inappropriate vacuum media. When an electrical discharge occurs between two electrodes under relatively low pressure, a beam with high-energy ions is generated to extract atoms from the surfaces of the targets when they collide [2].

The growing need for robust, lightweight materials has led to the development of numerous families of age-hardenable aluminium alloys. Precise control over the formation of alloy microstructures during solidification and subsequent thermomechanical processing is essential for producing high-quality, reliable cast and wrought products. The development of an equiaxed, fine-grained structure in castings has long been known to improve mechanical properties, reduce hot tearing and boost feeding to eliminate shrinkage porosity, resulting in a more uniform, finer distribution of second phases [3]. A thin film is a layer deposited onto a substrate with the objective of improving the physical properties of the surface for specific applications. Multiple layers, such as double, triple or quadruple, can be deposited simultaneously in a single layer [4]. Several methods are used to create thin films, one of which is plasma deposition, performed at low temperatures. Operating at low temperatures activates chemical reactions. Aluminium and its alloys are critical in various industries due to their excellent physical properties, high strength-to-weight ratio, strong corrosion resistance, ease of processing and forming, non-toxicity and recyclability [5, 6]. The Al-Cu-Mg-Fe-Ni forging alloy, known as aluminium alloy 2618, was developed for use in aerospace engine components and automotive applications. Its excellent high-temperature strength, reaching up to 238 °C, is achieve a combination of precipitation and dispersion hardening [7-11]. Corrosion is a modern dilemma, as the damage it causes to tools and equipment leads to substantial material and financial losses. Corrosion occurs in various forms and can be categorised into two main types: wet corrosion and dry corrosion. Wet corrosion is a corrosion process in which the liquid phase plays a key role, either through direct interaction or by serving as a medium for the reaction. On the contrary, dry corrosion involves the direct interaction between gas or vapour and the corroded material, without the presence of a liquid phase. Corrosion can be defined as the chemical interaction between a material and the surrounding atmosphere in direct contact with it, whether the atmosphere is air or any other chemical environment [12-14].

This study enhances the mechanical properties of turbocharger surfaces by depositing a thin film of aluminium dioxide (Al_2O_3) onto samples manufactured from aluminium alloy (AL2618). The coated samples were then tested for use in the manufacturing of turbocharger blades to achieve a protective layer with high efficiency, increased hardness and enhances corrosion resistance.

1.1 Pulsed laser deposition device

PLD has gained popularity in the production of multi-component thin films. High-temperature superconductors, compound semiconductors, dielectrics, ferroelectrics, gigantic magnetoresistance and electro-optic oxides, polymers and diverse heterostructure types have been extensively researched [15] by Heidelberg (1996) with a third edition scheduled for release in 2000. Large grain orientation and epitaxial films are produced by ablating the target material at pressures below 0.1 mb, either in an inert, reactive environment or in a vacuum. The primary mechanism for film formation involves the flow of atoms and ions interacting with molecules on the substrate surface. Assuming the creation of small-area films, measuring several square millimetres, PLD is a fast, simple and highly reliable process for experimentation. Thin films can be produced using a variety of materials without the need for hazardous or corrosive processes. The quick turnaround times enable the thorough examination of a wide range of chemicals and film doping variations. These factors make PLD especially appropriate for materials research and development. The target material is ablated at pressures of approximately 0:01 to produce epitaxial and large-grain-oriented films, either in inert or reactive atmospheres, or in a vacuum. In this process, small molecules and atoms/ions striking the substrate surface are the main sources of flux used to synthesise the films. The situation changes remarkably from one to several hundred mb. These circumstances encourage vapour-phase condensation and the formation of clusters and nanocrystals. These nanocrystals contain 10^2–10^6 atoms, with sizes ranging from 1–20 nm [16].

1.2 Alfa- Al2O3 layers

Alpha alumina (α-Al2O3) content determination is one of the primary applications of X-ray diffraction (XRD) analysis. However, notable variations are observed in the relative intensities of the principal XRD reflections depending on the morphological shapes of rhombohedral alumina due to the preferred orientation effect). Moreover, the X-ray diffraction power of a specimen may vary, complicating or eliminating the use of a reference material. As a result, comparing the intensities of certain reflections from a sample to those of a reference material can lead remarkable analytical errors. Using conventional XRD coupled with the Rietveld approach, the concentrations of alpha and beta alumina (β-Al2O3=Na2O•11Al2O3) were investigated in nine commercial ceramic alumina, three NIST standards and two unique grades of alumina. The morphology of the materials were also assessed using scanning electron microscopy (SEM) [17].

2. Experimental Work

This experiment was conducted under the following conditions: pressure of 3.3 $*10^{-2}$ bar, energy of 1520 MJ, frequency of 10 Hz and 500 impulses, as shown in Figure 1. After completing the deposition process, the turbine blade was examined at the Industrial Research and Development Center, where the properties of the blade were improved using the PLD device. A nanomaterial (ALfa- Al_2O_3) with a particle size of 30 ± 5 nm was deposited on the surface of the turbine blade (AL-2618). The device setup technical parameters are as follows: wavelengths of 532, 1064 and 1320 nm; pulse width of 10 ns; energy of 20—2000 mj; working frequency of 1–10 Hz; spot diameter of 1–8 mm; cooling method of water cooling + air cooling; total power of 300 W. The force applied by the Al_2O_3 particles to slow down recrystallisation can be expressed as follows [18]:

$$p_z = 3f\gamma/2r. \quad (1)$$

The average size of the particles (Al_2O_3) is r = (30 ± 5) * (10−7) m, the volume fraction is f = 0.83%, and the boundary energy is γ = 53.75 J/m2. According to the computation, the force Pz exerted by the Al_2O_3 particles is 15.6 MPa. Recrystallisation is prevented more effectively in 2618-(Al_2O_3) than in AA2618 because more Al_2O_3 particles exist in the latter. Similarly, the grain boundary velocity in 2618-(Al_2O_3) is lower than in AA2618 for the same reason (pz = 22.30 MN).

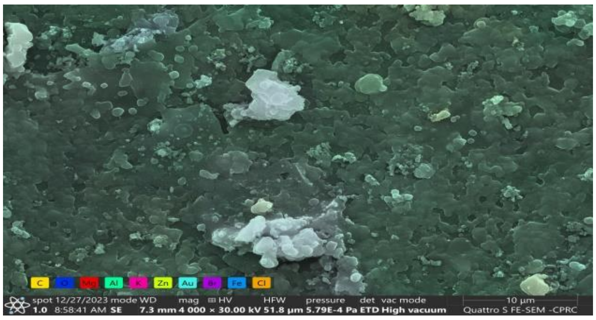
Fig. 1. Pulsed Laser Deposition Device

3. Results and Discussion

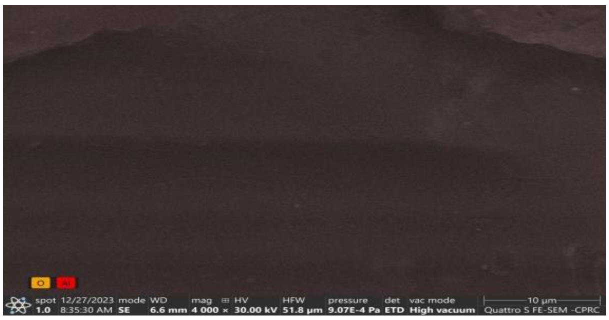
3.1 EDX test

Energy-dispersive X-ray spectroscopy (EDX) examination is the first step in material analysis. The distinctive pattern of the absorption bands indicates an improvement in the material composition as the chemical composition of small particles changes. The results showed an increase in compressive strength, enhanced ductility and higher hardness after depositing a layer of Al2O3 on the composite material using glow discharge plasma, as shown in Figure 2.

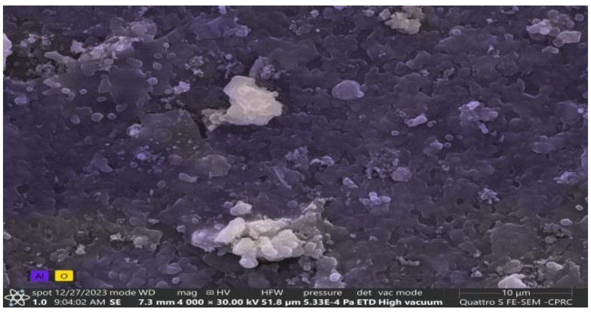
A. Before Deposition without Filter



B. After Deposition without Filter



C. Before Deposition with Filter



D. After Deposition with Filter

Fig. 2. (EDX) Examination for Turbocharger Blades

The atomic and weight percentages of oxygen (O) increased because of the deposition, whereas those of aluminium (Al) decreased. Tables 1–2 show the atomic and weight percentages for elements O and Al before and after deposition.

Table 1
(EDX) Examination for Turbocharger Blades before Deposition

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
O	3.6	0.6	2.2	0.3
Al	96.4	0.3	97.8	0.3

Table 2
(EDX) Examination for Turbocharger Blades after Deposition

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
O	13.8	0.8	8.7	0.5
Al	86.2	0.3	91.3	0.3

3.2 Hardness test

When determining a material's hardness, the Brinell and Rockwell procedures require considerable force and create a broad surface impression. Although optical measurement is incorporated into the Vickers hardness testing method, it is unsuitable for permanently assembled components or machinery that has been installed. Leeb hardness testing instruments use indirect and rebound techniques to quantify hardness. However, notable differences are found when converting Leeb hardness values to Brinell, Rockwell and Vickers hardness scales. Ultrasonic hardness testers, on the contrary, leave a small imprint on the surface of the material and quantify hardness using the high-accuracy ultrasonic contact impedance (UCI) method. Nonetheless, an ultrasonic hardness tester tends to be more expensive due to its high level of precision and nearly nondestructive nature of the assessment it provides [19]. The technical details are as follows: measurement range of 170–960 HLD; measurement direction of 0°–360°; hardness scale of HL, HB, HRB, HRC, HRA, HV and HS. Figure 3 shows that the maximum load values are 500 N, 50 kg, 110 Lb and 1800 Oz; the load division values are 0.1 N, 0.01 kg, 0.01 Lb and 1O z; the accuracy is ±1%.

The results of the hardness test for turbocharger blades before and after deposition are displayed in Table 3 and Figure 4.

Fig. 3. Hardness Tester

Table 3,
Hardness Test for Turbocharger Blades.

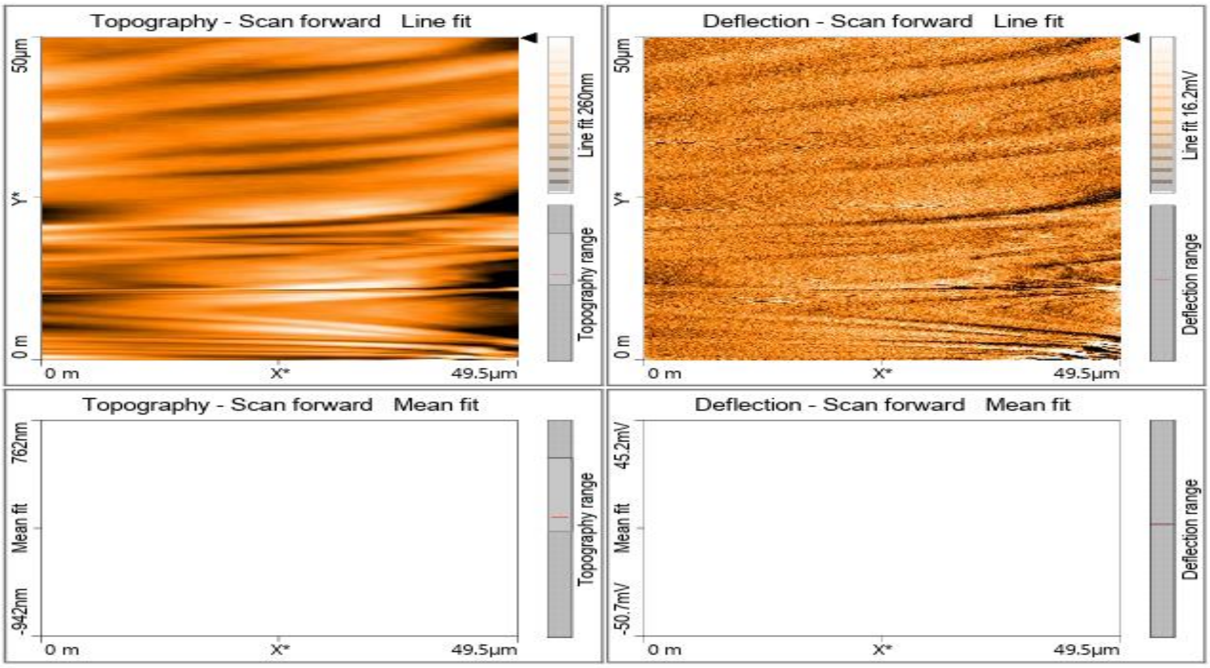
Sample number.	Before deposition (HLD)	After deposition (HLD)
1	685	781

(a) Before deposition (HLD) **(b) After deposition (HLD)**

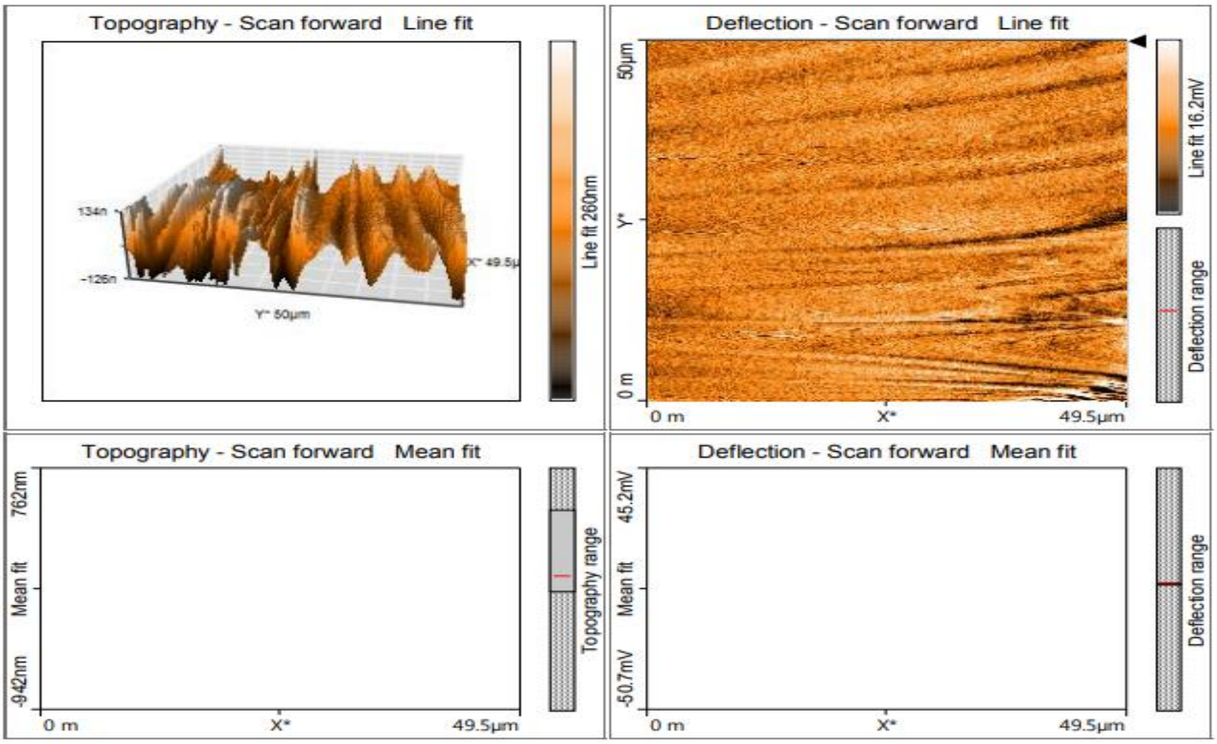
Fig. 4. Hardness Tester for Turbocharger Blades

3.3 Surface topography using AFM test

Atomic force microscopy (AFM), also known as scanning probe microscopy, provides near-atomic resolution images for measurement. AFM can measure surface roughness down to the angstrom scale. In addition to surface images, AFM analysis can offer quantitative estimates of feature sizes, such as step heights and other dimensions. The distinctive pattern of absorption bands indicates an improvement. Figures 5–8 illustrate the decline in the value of *x* from 49.5 µm to 22.8 µm. Moreover, qualitative mapping of additional physical characteristics, such as adhesion, modulus, dopant distribution, conductivity, surface potential, electric field and magnetic domains, may be achieved using sophisticated AFM measurement modes.



A- 2D



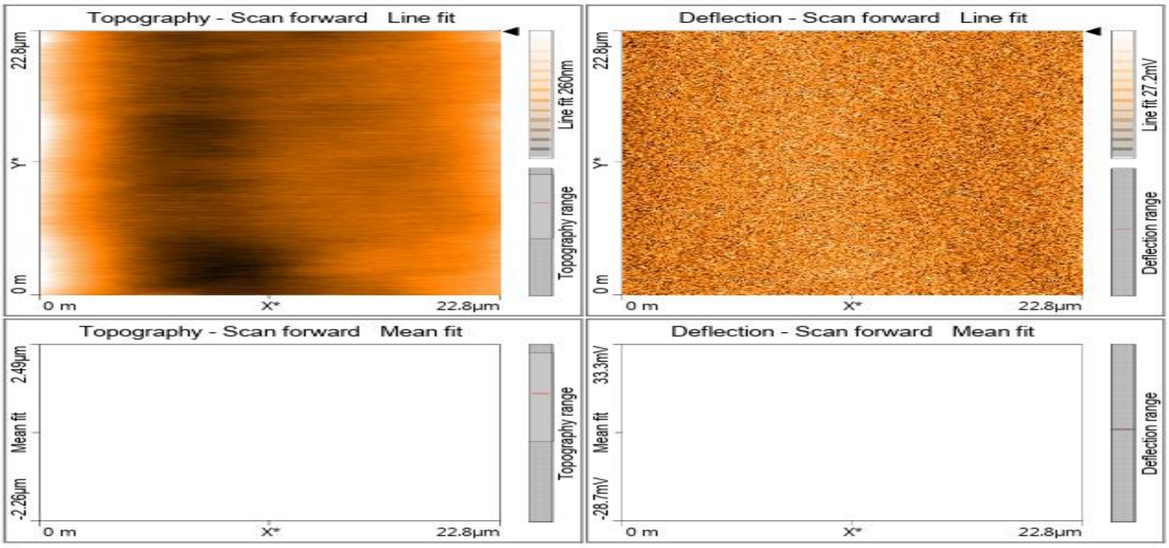
B- 3D

Fig. 5. AFM Tester for Turbocharger Blades before Deposition.

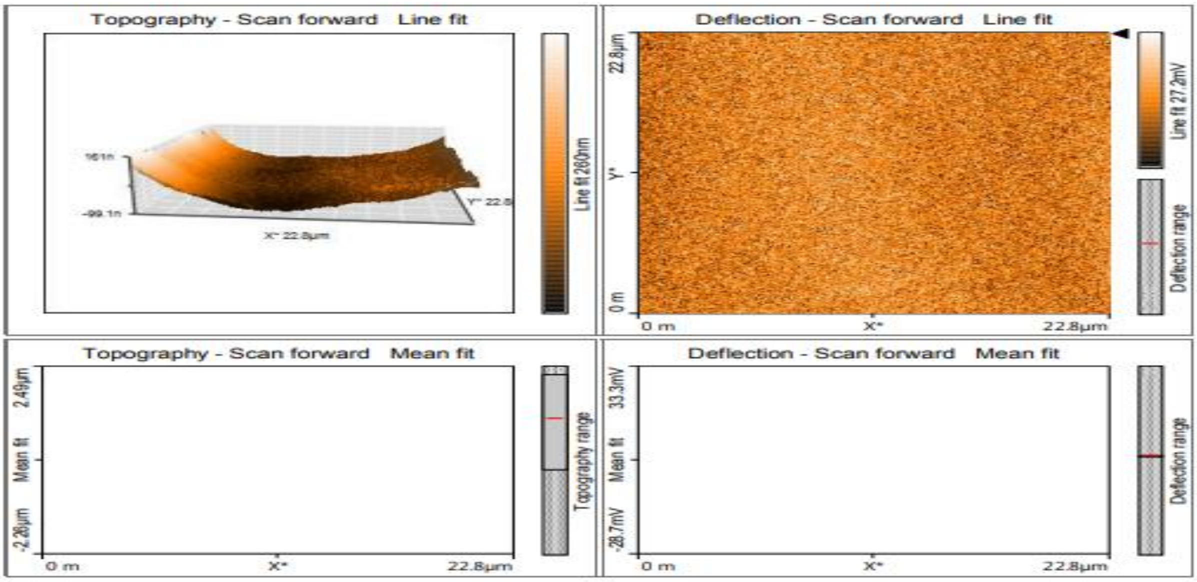
Parameter:

-- Scan group --		Setpoint	= 20nN	Firmware ver.	= 3.1.3.13
Image size	= 50µm	P-Gain	= 10000	Controller S/N	= 023-12-147
Scan direction	= Up	I-Gain	= 1000	-- Module --	
Time/Line	= 1 s	D-Gain	= 0	Controller Board	= 2
Points	= 256	Tip voltage	= 0nV	AFM Basic Module	= 3
Lines	= 256	Feedback mode	= Free running	AFM Dynamic Module	= 2
X-Slope	= 0 °	Feedback algo.	= Adaptive PID	AFM Extension Module	= 1
Y-Slope	= 0 °	Error range	= 20 V	Video Module	= 0
Rotation	= 0 °	-- Global --		Signal Module S	= 0
X-Pos	= 0 m	Measurement environment	= Air	Signal Module A	= 0
Y-Pos	= 0 m	Operating mode	= Static Force	USB Module	= 5
Z-Plane	= 0 m	Cantilever type	= CONTR	Nanosurf Report	= 6
Overscan	= 5 %	Head type	= EZ2-FlexAFM	Scripting Interface	= 0
Const.Height-Mode	= Disabled	Scan head	= 38-12-168.hed	Spectroscopy Module	= 0
Date	= 17-01-2024	Laser working point	= 47.6%	Lithography Module	= 0
Time	= 11:19:54	Deflection offset	= -5.0%		
-- Feedback group --		Software ver.	= 3.1.0.22		

Fig. 6. AFM Tester Parameters for Turbocharger Blades before Deposition.



A- 2D



B-3D

Fig. 7. AFM Tester for Turbocharger Blades after Deposition.

Parameter:

-- Scan group --		Setpoint	= 20nN	Firmware ver.	= 3.1.3.13
Image size	= 23µm	P-Gain	= 10000	Controller S/N	= 023-12-147
Scan direction	= Up	I-Gain	= 1000	-- Module --	
Time/Line	= 1 s	D-Gain	= 0	Controller Board	= 2
Points	= 256	Tip voltage	= 0nV	AFM Basic Module	= 3
Lines	= 256	Feedback mode	= Free running	AFM Dynamic Module	= 2
X-Slope	= 0 °	Feedback algo.	= Adaptive PID	AFM Extension Module	= 1
Y-Slope	= 0 °	Error range	= 20 V	Video Module	= 0
Rotation	= 0 °	-- Global --		Signal Module S	= 0
X-Pos	= 0 m	Measurement environment	= Air	Signal Module A	= 0
Y-Pos	= 0 m	Operating mode	= Static Force	USB Module	= 5
Z-Plane	= 0 m	Cantilever type	= CONTR	Nanosurf Report	= 6
Overscan	= 5 %	Head type	= EZ2-FlexAFM	Scripting Interface	= 0
Const.Height-Mode	= Disabled	Scan head	= 38-12-168.hed	Spectroscopy Module	= 0
Date	= 17-01-2024	Laser working point	= 0.0%	Lithography Module	= 0
Time	= 12:11:43	Deflection offset	= -1.2%		
-- Feedback group --		Software ver.	= 3.1.0.22		

Fig. 8. AFM Tester Parameters for Turbocharger Blades before Deposition

4. Conclusions

1. The mechanical properties of a turbocharger blade made of aluminium alloy (AL-2618) and coated with Al_2O_3 are explored in this work.
2. A nanolayer of Al_2O_3 was deposited using a PLD device, and the samples were examined after deposition using an EDX device, hardness tester and AFM.
3. The atomic percentage of oxygen deposited on the surface of the turbocharger blade ranges from 0.6% to 0.8%.
4. The hardness of the samples increased from 685 HLD to 781 HLD.
5. After deposition, the roughness asperities *x* decreased in height from 49.5 µm to 22.8 µm due to the nanolayer deposited using a PLD device.

References

[1] Kaka Ma, Yufeng Zheng, Sriswaroop Dasari, Dalong Zhang, Hamish L. Fraser & Rajarshi Banerjee ," Precipitation in nanostructured alloys: A brief review", Volume 46, pages 250–257, (2021).

[2] V. I. Arkhipenko, S, M, Zgirouski, A. A. Kirillov, and L. V. Simonchik, Plasma Physics Reports, 28, 930 (2002).

[3] Kun Yu, Wenxian Li, Songrui Li, Jun Zhao," Mechanical properties and microstructure of aluminum alloy 2618 with Al3(Sc, Zr) phases", Materials Science and Engineering: A,Volume 368, Issues 1–2, 15 March 2004, Pages 88-93.

[4] P.Malekzadeh,"A differential Quadrature Nonlinear Free Vibration Analysis of Laminated Composite Skew Thin Plates", Journal of thin wall Structures ,Vol.(45),pp.237-250,January 2007.

[5] J.E. Samad, J.A. Nychka, Wettability of biomimetic thermally grown aluminum oxide coatings, Bioinsp. Biomim. 6 (2011) 016004–016009.

[6] J.F. Joanny, Polyelectrolyte adsorption and charge inversion, Eur. Phys. J. B 9,(1999).

[7] I. N. A. Oguocha, S. Yannacopoulos and Y. Jin, The structure of AIXFeNi phase in Al-Cu-Mg-Fe-Ni, J. Mater. Sci., Vol. 31 (1996), 5615–5621.

[8] J. H. Wang, D. Q. Yi and X. P. Su, et al., Influence of deformation ageing treatment on microstructure and properties of aluminum alloy 2618, Mater. Charact. Vol. 59 (2008), 965–968.

[9] Z. W. Du, G. J. Wang and X. L. Han, et al., Microstructural evolution after creep in aluminum alloy 2618, J. Mater. Sci., Vol. 47 (2012), 2541–2547

[10] Akeel Dhahir Subhi and Adnan Mohsen Abd," Improving Wear Properties of 392 Al Alloy Using Centrifugal Casting", Department of Production Engineering and Metallurgy / University of Technology/ Baghdad, Vol. 15 No. 1 (2019): Al-Khwarizmi Engineering Journal

[11] Alalkawi H. J. M., Ali Yousuf K Khenyab andAbduljabar H. Ali," Improvement of Mechanical and Fatigue Properties for Aluminum Alloy 7049 By Using Nano Composites Technique", Department of Electromechanical Engineering/ University of Technology/ Baghdad/ Iraq, DOI: https://doi.org/10.22153/kej.2019.08.001, Vol. 15 No. 1 (2019): Al-Khwarizmi Engineering Journal.

[12] N. Mathan Kumar a, S. Senthil Kumaran b, L.A. Kumaraswamidhas a," An investigation of mechanical properties and corrosion resistance of Al2618 alloy reinforced with Si3N4, AlN and ZrB2 composites", Journal of Alloys and Compounds Volume 652, 15 December 2015, Pages 244-249.

[13] Saad Abdel Wahed Tohme1, Hana Khaled Khalaf, Nour Ali Nasser, Ahmed Dawoud Salman,"Manufacturing of aluminum alloy reinforced polymer and the possibility of using it in a solar heater", Industrial Research and Development Authority - Renewable Energy and Environment Research Center.

[14] Aseel Basim Abdul-Hussein, Fadhel Abbas Hashim and Tamara Raad Kadhim," Effect of Nano Powder on Mechanical and Physical Properties of Glass Fiber Reinforced Epoxy Composite",Department of Materials

Engineering/ University of Technology, Vol. 12 No. 3 (2016): 2016.

[15] D. Bäuerle: Laser Processing and Chemistry, 2nd ed. (Springer, Berlin).

[16] W. Marine, B. Luk'yanchuk, M. Sentis: Le VIDE Science, technique et applications, 2=4, 440 (1998).

[17] Frank Feret,Daniel Roy and Clermont Boulanger," Determination of alpha and beta alumina in ceramic alumina by X-ray diffraction", July 2000,Spectrochimica Act Part B Atomic Spectroscopy 55(7):1051-1061.

[18] J.H. Wang and D.Q. Yi ,"Preparation and Properties of Alloy 2618 Reinforced by Submicron AlN Particles", (Submitted February 15, 2005; in revised form November 17, 2005).

[19] Ifeyinwa Obianyo,"LABORATORY MANUAL FOR HARDNESS TEST", Nile University of Nigeria, Abuja ,March 2019.

تحسين الخواص الميكانيكية لسطح الشاحن التوربيني المصنع من سبيكة AL2618 باستخدام جهاز PLD معAl2O3

سارة سعد فرج[1]، نبيل حسن هادي[2]*

[1]قسم الهندسة الميكانيكية، جامعة بغداد، بغداد، العراق

[2]قسام هندسة الطيران، جامعة بغداد، بغداد، العراق

*البريد الالكتروني : Dr.Nabil.Hassan@coeng.uobaghdad.edu.iq

المستخلص

ترسيب الليزر النبضي (PLD) تقنية واسعة الانتشار لطلاء سطح المعادن بالأغشية الرقيقة .تم في هذا البحث دراسة مرحلة البنية المجهرية وتركيب وتأثير الطلاء المصنع من مادة نانوية (Alfa- Al2O3)، وانجز الترسيب بجهاز الليزر النبضي لتحسين الأداء الميكانيكي لشفرات الشاحن التوربيني المصنعه من سبائك الألومنيوم (AL-2618) ، من مميزات استخدام التقنية تقليل التآكل بالكلال والتآكل الكيمياوي لشفرات الشاحن التوربيني ، ولضمان الصلابة العالية والعمر الطويل الأمد، بواسطه جهاز الترسيب الليزر النبضي يتم ترسيب طبقة بسمك(10µm) من ثاني أكسيد الألومنيوم النانوي (Al2O3) على سطح شفرات الشاحن التوربيني .بعد اجراء الفحصوصات المختبريه ،نلاحظ تحسن الخواص الميكانيكية لسطح الشاحن التوربيني. حيث تم اجراء اختبار الصلابة واختبار (AFM) و (EDX) قبل وبعد عملية الترسيب .وقد وجد أنه بعد ترسيب طبقة النانوية من ثاني أكسيد الألومنيوم(Al2O3) ، زادت الصلابة وقل التآكل.