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Surface modification of aluminium - lithium alloy using prenitriding option and Si_xN_y coating deposition

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ABSTRACT

Purpose: EU directive of CO_2 emission reduction causes many applied technologies to become unprofitable considering environmental protection. Due to that, there is an urgent need to create new or modify existing technological solutions - especially in the field of materials engineering. One of the options to reduce CO_2 emission is replacement of parts made of steel by Aluminum -Lithium alloys mainly in such branches like automotive and aircraft industry.

Design/methodology/approach: Prenitriding option was carried out in low pressure plasma discharge mode, at a substrate temperature below 200ºC followed by the deposition of 500 nm thick Si_xN_y coating. Morphology and mechanical properties were compared with substrate without prenitriding treatment.

Findings: In this paper, first promising results of surface treatment with the use of prenitriding option of Al-Li alloy are presented. The results showed that the wear resistance of the Al-Li alloy may be modified by application of plasma enhanced CVD [1-4]. Two different types of surface modification were applied.

Research limitations/implications: In case of vehicles' parts, subjected to wear or/and contact fatigue a use of light weight alloys gives rise to many difficulties, caused by their low surface parameters. The aluminium alloys applied for elements operated in wear contact even with the best possible mechanical properties at the moment, it is limited due to still not enough tribological properties. The research in this field may bring another reduction of vehicles total weight.

Practical implications: At present, ultra light materials with high durability are elaborated for components, e.g. in automotive industry mainly to realize a light gearbox.

Originality/value: Functional Gradient Coatings (FGC) was deposited below temperature which could cause destruction of "tailored" structure of the substrate.

Keywords: Aluminium alloy; Prenitriding; Si_xN_y coating

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1. Introduction

Reducing vehicle weight for limiting energy consumption, in particular mass reduction of engine parts, is one of the most important challenges in the field of modern transport, especially in automotive and aircraft industry [1-4]. Low density materials like titanium, aluminium and magnesium, mentioned above, have a significant and promising potential as a substitute for steel. One of the modern materials ranked among a group of high-advanced ultra light materials is aluminum-lithium alloy. Al-Li is distinguished by reducing density without decreasing strength, toughness, corrosion resistance [5].

However, forming Al_2O_3 on the surface, it is affected by high Al reactivity with oxygen causing wear increase. This phenomenon is generated mainly due to porosity and poor adhesion of Al_2O_3 to the substrate. From scientific literature analysis, it follows that this disadvantage can be overcome by surface modification using such processes like [6]: physical vapour deposition (PVD), plasma assisted chemical vapour deposition (PACVD) [7], magnetron sputtering, ion implantation [8], pulse laser deposition (PLD) [9-11], fluidized bed [15], thermal spraying, [12, 13]. However, only few of them seem to be useful due to structure sensitively of aluminum alloys to deposition temperature over 200°C.

Independently, a special emphasis is given to plasma nitrided of aluminum alloys reported by [14-17]. Applied ion bombardment could involve sputtering of the substrate to remove Al_2O_3 and accelerate reaction of nitride ions with bare substrate. However, due to close packing of aluminum alloys' unit cell, and from physicochemical point of view, it is very difficult to receive relatively deep concentration profile of nitride solid solution with thin AlN layer on the surface. In contrast to this, mainly AlN layer is formed which could cause discontinuity of mechanical properties between layer and substrate. Additionally, in the light of presented results, it seems that to overcome tribological problems of Al alloys it is necessary to apply Functional Gradient Coatings (FGC) below the temperature which could cause destruction of "tailored" structure on the substrate. In our opinion the point was left without due consideration.

The aim of this work was to improve the lightweight alloys properties on the way of application the low pressure processes for surface modification of aluminum lithium alloy. The improvement of properties of treated Al-Li substrates was proved by series of studied including nanohardness, SEM and AFM investigations.

2. Experimental

The material used in this work was Al 2wt.%Li alloy. The surface of the samples was modified using Radio Frequency Chemical Vapour Deposition technique (13.56 MHz, 300 W) with application of N_2 and SiH_4 as nitrogen and silicon precursors.

The prenitriding and SixNy coating deposition were carried out in RFCVD equipment. Table 1 presents designations of an unmodified sample (Process 1) with Si_xN_y coating (Process 2) and after nitriding pre-treatment and Si_xN_y coating deposition (Process 3).To remove oxygen from the surface, each deposition process was started with argon-plasma etching. The sample I was pre-treated and then nitrogenated with nitrogen plasma. The sample II was subjected to the following sequence of stages. Firstly, it was pre-treated and nitrogenated (in the same way as the sample I). Then, it was once more subjected to Ar-plasma etching and finally, a-SiN_x: H layer was deposited with application of $SiH_4/N_2/Ar$ gas mixture. The sample III was covered with a-SiN_x: H layer deposited directly onto pre-treated alloy surface. Various SiH_4/N_2 ratios were applied for the samples II and III. Table 1 presents designations of an unmodified. The processing parameters: flow of gas-mixture components, substrate temperature – T_s, gas pressure in the chamber – p, plasma RF generator power – P_{RF} and time of deposition – t, were precisely controlled (Table 1).

Table 1.
Technological parameters of RF CVD applied in the Al-Li alloy surface modification

Sample	Process	Gas flow [cm^3/min]			T_s [K]	p [Pa]	P_{RF} [W]	t [s]
		Ar	N_2	$SiH_4/N_2/Ar$				
I	1. Ar-plasma etching	200	-	-	320	53.3	40	1200
	2. Nitrogenation	-	80	-	465	93.3	100	7200
II	1. Ar-plasma etching	200	-	-	500	53.3	8	600
	2. a-SiN_x:H layer deposition	-	-	8/24/80	500	53.3	50	480
III	1. Ar-plasma etching	200	-	-	320	53.3	40	1200
	2. Nitrogenation	-	80	-	465	93.3	100	720
	3. Ar-plasma etching	200	-	-	500	53.3	8	600
	4. a-SiN_x:H layer deposition	-	-	8/16/80	500	53.3	50	480

3. Results and discussion

Figures 1a, b show SEM images of Al-Li metallographic cross-sections of samples with Si_xN_y coating without and with prenitriding treatment. It is visible that the 500 nm thick coating has a uniform and dense structure. Nanoindentation test revealed that prenitriding treatment of Al – Li alloy caused increase nanohardness after Si_xN_y coating deposition to about 10.8 GPa comparing with sample with Si_xN_y coating only – 8.0 GPa (Figure 2). From an average grains height analysis, it results that during coating deposition after prenitriding, on the sample smaller (about two times in diameter) grains are formed in comparison with the sample without nitriding pre-treatment (Figure 3). Our experiments point out that when using both: the fine crystalline structure of the coating and prenitriding treatment enhance the hardness of the coating (Process 3). During prenitriding treatment, the surface Al – Li alloy is strongly activated and more preferable sites for crystallization of Si_xN_y grains are available.

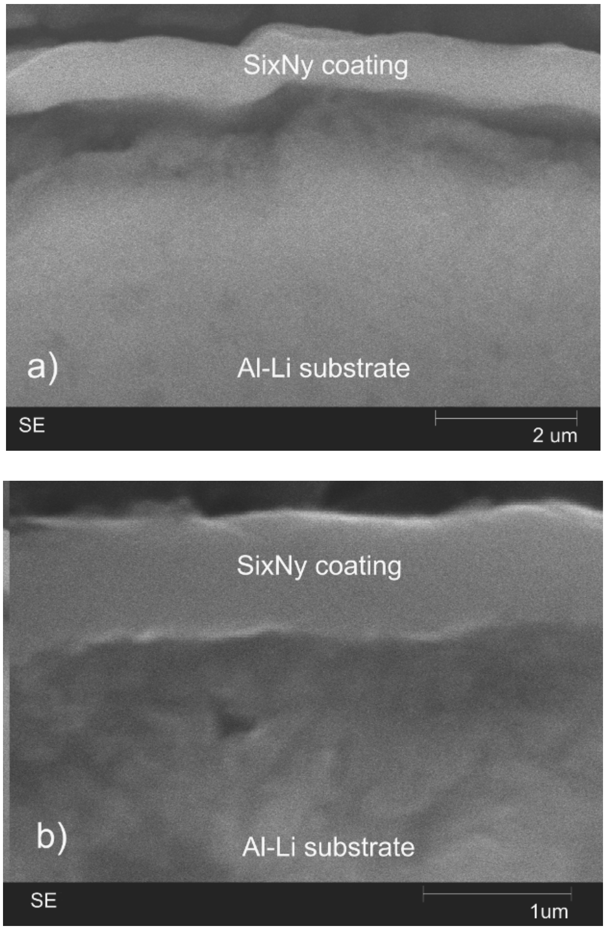

Fig. 1. SEM images of Al-Li metallographic cross-sections with Si_xN_y coating (sample 2) (a) without and (b) with prenitriding treatment (sample 3), respectively

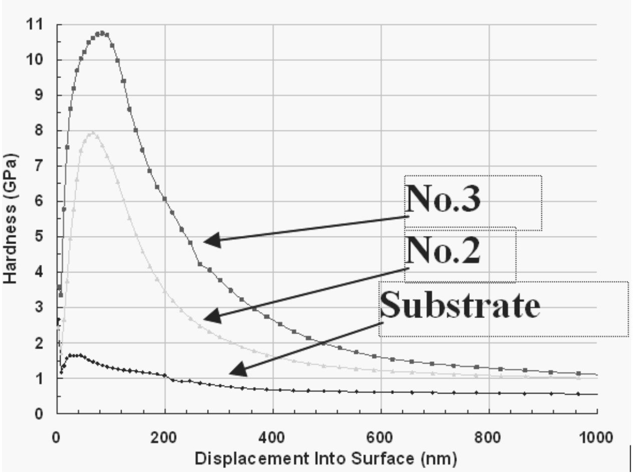

Fig. 2. Microhardness profiles of Al-Li substrate; blue line - bare substrate; yellow line - after Si_xN_y coating deposition (sample 2); pink line - after prenitriding treatment and Si_xN_y coating deposition (sample 3), respectively

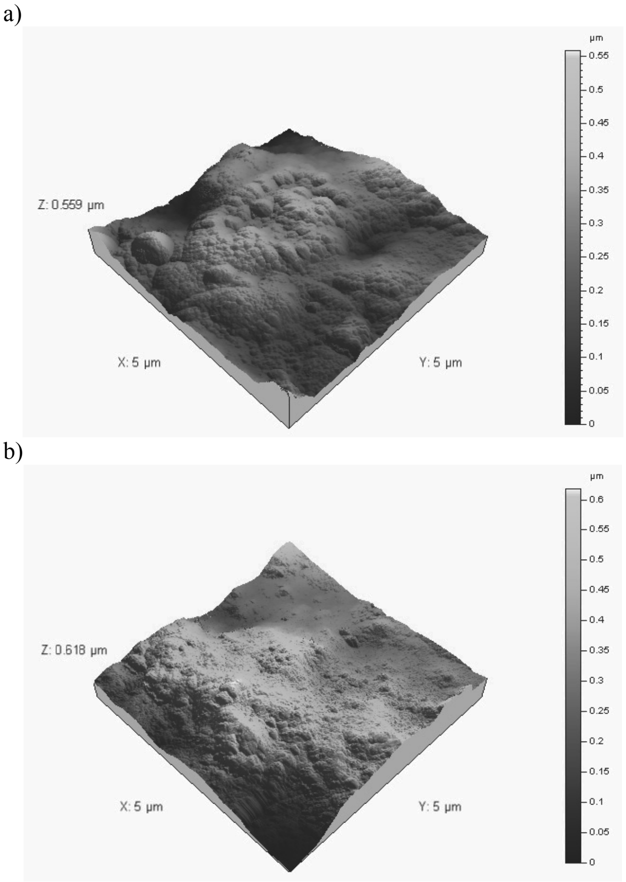

Fig. 3. AFM images of Al-Li substrate (a) after Si_xN_y coating deposition – (sample 2); (b) after prenitriding treatment and Si_xN_y coating deposition - (sample 3), respectively

4. Conclusions

The present results show that RFCVD method allows to produce homogeneous thin Si_xN_y coating. Applying prenitriding option causes decrease in grains size and increase in hardness of Si_xN_y coating comparing to the sample without prenitriding, what can influence on increase of wear resistance [19]. It is a promising method to enhance mechanical properties of aluminium alloy surface without destruction of "tailored" structure of the substrate because temperature of deposition is below 200°C. However, more experiments need to be done to optimise mechanical properties and clarify prenitriding influence.

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