Mechanical and Corrosion behavior of plasma nitrated tests on SS316L & Ti6Al7NB

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Abstract:

Due to its great biocompatibility, strong corrosion resistance, and specific strength, Ti and its alloys offer the best features for biomedical applications. It has been determined that Ti-6Al-7Nb is a suitable alternative for the Ti-6Al-4V alloy, which has been used in medical applications for many years, and it has been approved for use in clinical. Biomaterials are the substances that are utilised to sustain a system or substitute for a biological tissue. For increasing their viability, the most popular metal, SS316L, and another metal, Ti6A7NB, which has the necessary qualities, were chosen. Despite their strength, SS316L and Ti6A7NB exhibit mechanical characteristics when utilised in biological systems. Since they must be made much more suitable to be used as a biomaterial, plasma nitriding and salt baths are used to slow down corrosion and make the material considerably more compact. A heat treatment method called plasma nitriding and salt baths diffuses nitrogen ions over the surface, creating nitrides while lowering reactivity and enhancing corrosion resistance. The effects of nitriding and salt bathing these metals for varying lengths of time 10 hours and 24 hours, respectively on their characteristics are investigated. To investigate the structural topography and composition, SEM and EDAX are used. To demonstrate how plasma nitriding and salt baths affect the metals hardness, the Vickers hardness test is used.

Keywords: Hardness, Mechanical Properties, Plasma Nitriding, SS316L and Ti6A7NB.

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1. Introduction

Since they are utilised to restore damaged biological components, biomaterials are extremely important to humanity. Following acceptable mechanical strength, good wear, and exceptional corrosion resistance in a highly corrosive environment produced by the human body, the most crucial criteria for a biomaterial is to be accepted by the human body. The most often utilised materials in the production of biomaterials are pure titanium, titanium alloys, titanium-aluminum-vanadium-chrome alloys, and 316 L stainless steel. Ti and its alloys offer the most favourable qualities for biomedical applications among biocompatible metal alloys because of its particular strength, strong corrosion resistance, and excellent biocompatibility. Researchers have focused on the problem of furthering the

development of Ti-based alloys with improved characteristics for medical applications. Ti-6Al-4V is the most used Ti-based alloy, however new reports suggest that it has high toxicity to humans, resulting in health issues. To solve this problem, non-toxic titanium alloys including Nb, Zr, Ta, Mo, Fe, etc. have been created. One of these alloys, Ti-6Al-7Nb, has received clinical approval and has shown to be a suitable alternative for the Ti-6Al-4V alloy, which has been utilised for medical purposes for many years. Shunts, pacemakers, bone transplants, and dental implants are the most popular examples of biomaterials. A biomaterial is also known as implants. Polymers, ceramics, plastics, and metals may all be used to create these biomaterials. Metals are utilised to make the majority of materials. These substances must be biocompatible and not have an impact on the biological system[1]. There is a higher likelihood that metal will corrode owing to the production of oxides since a biological system is made up of several fluids [2]. Plasma nitriding becomes more prominent in such circumstances. A surface hardening method called plasma nitriding was created based on the phenomena and traits of glow discharge plasma [3]. By passing a DC voltage between two electrodes in a vacuum diode, the phenomena of glow discharge was first seen and explored. Simply said, the plasma nitriding method involves enriching the workpiece's surface layer with nitrogen through a thermochemical process. Nitriding may take place in a variety of media, including liquid and gas, but when gas is utilised, the process is known as plasma nitriding. N2 or ammonia are the gases utilised in plasma nitriding, with argon gas originally being used for pre-processing, or the cleaning step. Particles are accelerated and then strike the cathode, heating it and transmitting all of their kinetic energy. Gas particles need to have a sizable mean free path in order to build speed for collision with the substrate before interacting with another gas particle and transfer enough kinetic energy to do so. To enhance the mean free path of the accelerated particles, this process and the majority of plasma processes operate in vacuum. Typically, plasma nitriding is done at pressures of between 100 and 1000 Pa. Since other procedures require far greater vacuum values, this pressure is regarded as a rough vacuum. It is between 450 and 700 °C [4]. The gas is first heated to a very high temperature, which causes the ions to diffuse into the metal's surface and produce nitrides, decreasing the metal's reactivity and lowering corrosion [5,6]. Thus, plasma nitration of the metals greatly increases their biocompatibility. Plasma nitriding may be done at a variety of temperatures and times, with 10 and 24 hours being the most popular. A variation in the material's characteristics may result from varying temperatures and time of exposure [7-9]. In order to pick the best material and advise the appropriate period, the chosen metals are treated, and their characteristics are investigated.

2. Materials and Methods

2.1 SS316L

Stainless steel, CoCr alloys, and Ti alloys are the three metal implants that are now most often utilised. Due to its near to 18 wt% Cr and 8 wt% Ni content, SS316L utilised for implants is stronger and more corrosion-resistant than other steel kinds [10-12]. Additionally, SS316L has a higher molybdenum concentration than other stainless steels, which improves corrosion resistance. It also has a lower carbon content, below 0.03%, which improves resistance to chlorides[13,14]. Table1 discusses a comprehensive composition in depth.

Table 1 weight-based SS316L composition

S.No	Element	Composition (%)
1	Carbon	0.03
2	Magnesium	2
3	Chromium	16 - 18
4	Silicon	0.75
5	Phosphorus	0.045
6	Sulphur	0.03
7	Molybdenum	2 - 3
8	Iron	remaining

2.2 Ti6A7NB

Considering how light titanium is, its impact is far greater. When compared to cast CoCrMo alloys and stainless steels, its density, which is just 4.5 g/cm3, is significantly lower [15,16]. Excellent tensile strength and pitting corrosion resistance are two characteristics of Ti6Al4V. It is used in delicate tissues because of its lighter weight. When Ni is added to titanium, alloys are created that have shape memory properties, making them appropriate for a variety of uses, including dental repair wiring [17,18]. Table 2 displays Ti6A7NB's precise chemical composition.

Table 2 Ti6A7NB by weight composition

S.No	Element	Composition (%)
1	Vanadium	3.5% - 4.5%
2	Aluminium	3.5% - 6.75%
3	Iron	Less than 0.3%
4	Nitrogen and hydrogen	0.15%
5	Oxygen	Less than 0.2%
6	Titanium	remaining

2.3 Plasma Nitriding

Collectible metals were initially wire-cut EDM chopped into smaller pieces and surface ground with 100 grit emery paper for a mirror sheen. After processing, these metals are then nitrided for various lengths of time separately - SS316l and Ti6A7NB for a total of 24 hours. The same quantity during a 10-hour period. The temperature was 530°C for the 24 hour cycle and 485°C for the 10-hour cycle. The metal pieces' surface colour revealed a tiny variation as a result of heat treatment, and even a small change in temperature can affect colour. On the surface of the metals, there are a number of areas that are both black and grey. By looking at the surface, a definite variation in hue may be detected. There are places that are both dark and light grey.

3. Experimental Setup

As seen in Fig.1, the investigations were carried out in the electrochemical work station on the biological SP 300 machine. In these tests, a cell containing three electrodes such as counter electrode, a working electrode, and a reference electrode are used. A three electrode arrangement is another name for this set up. A diamond indenter in the shape of a square is used to measure the hardness of Micro Vicker. The most popular timeframes for plasma nitriding are 10 hours and 24 hours. Temperatures can also vary. The materials characteristics may change depending on the period of exposure and the temperature at which they are evaluated using the equipment that is used.

Fig. 1. SP 300 biological devices

4. Results and Discussions

4.1 SEM Analysis

Both SS316L and Ti6Al4V were nitrided for 24 hours and viewed using a scanning electron microscope (SEM) at various magnifications ranging from 2KX to 100KX. EDAX was also performed to determine the atomic composition. The SEM pictures of SS316L for a 24-hour nitrided sample are shown in Fig.2. Because of the production of nitrides with iron, crystal structures in SEM images can be seen to be white in colour.

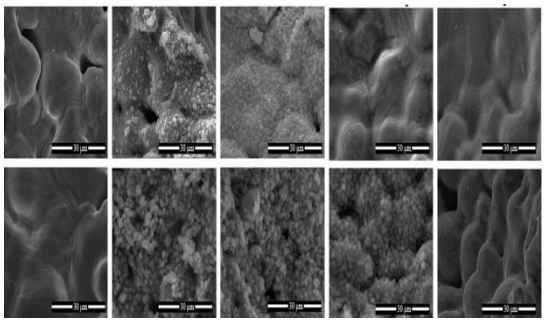

Fig. 2. SS316L SEM pictures

Looking at the composition from the EDAX test result, presented in Table 3, where the quantity of nitrogen can be observed as 10.26%, lends considerably more credence to this claim. There is originally no nitrogen present. Despite the fact that the percentage by weight is just 10%, the atomic percentage is 26.77, which suggests that there are more nitrogen atoms present due to increased nitride production.

Table 3 SS316L post-plasma nitriding EDAX analysis

S.No	Element	% weight	Atomic %
1	N	10.26	26.77
2	O	8.35	19.07
3	Al	0.53	0.72
4	Si	0.72	0.93
5	Ni	6.35	3.95
6	TI	0.56	0.43
7	V	0.54	0.39
8	Cr	17.74	12.46
9	Mn	1.04	0.69
10	Fe	51.42	33.64
11	Mo	2.49	0.95

To enhance the mean free path of the accelerated particles, this process and the majority of plasma processes operate in vacuum. Typically, plasma nitriding is done at pressures of between 100 and 1000 Pa. Since other procedures require far greater vacuum values, this pressure is regarded as a rough vacuum.

4.2 Micro Vickers hardness

Using a diamond indenter with a square shape, the Vickers micro hardness test was performed. To support the Vickers hardness test, plasma nitriding is proven to have improved the mechanical characteristics of metals. Table 4 displays the samples' hardness number values.

Table 4. Values of the Micro Vicker's Hardness Test (Averages)

S. No.	Sample Tested	Micro Vicker's Hardness Number (HV)
1	SS316L without Nitrided (10 hrs)	152
2	SS316L (10 hrs Nitrided)	201.4
3	SS316L without Nitrided (24 hrs)	354.8
4	SS316L (24 hrs Nitrided)	607.4
5	Ti6Al4V without Nitrided (10 hrs)	178
6	Ti6Al4V (10 hrs Nitrided)	328.4
7	Ti6Al4V without Nitrided (24 hrs)	242.8
8	Ti6Al4V (24 hrs Nitrided)	359.4

5. Conclusion

Titanium alloys are an appealing material for use in many engineering sectors because of their distinctive mix of strong mechanical qualities and great corrosion resistance. The metallic biomaterials' hardness has been significantly affected by plasma nitriding. By generating nitrides with the primary component, it also brought about a change in the topology of the metals' structural molecules. The increase in hardness from the un-nitrided sample is around 50HV, whereas the hardness of SS316L exhibited a negligible rise for the 10 hour nitride sample. The rise from a 10 hour sample to a 24 hour sample was significant, with a very large difference. There was approximately a 406 HV difference. The rise in hardness for Ti6Al4V was moderate, not particularly substantial. However, there was very little variation at around 31HV between the 10hr sample and the 24hr sample.

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