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ORIGINAL RESEARCH ARTICLE

MITIGATION OF THE WEAR FAILURE OF Ti-6Al-4V DENTAL IMPLANT USING NATURAL AND ARTIFICIAL AGEING TREATMENT

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ABSTRACT

Ti-6Al-4V alloy has been in use as dental implants due to its favourable mechanical properties but wears off over a period of time in the oral cavity. Therefore, this research aimed at using natural and artificial ageing to mitigates the wear failure of Ti-6Al-4V dental biomedical implant. The as received Ti-6Al-4V alloy was sectioned under flowing cooling conditions to 1.4mm x 1.4mm x 0.3mm and then heat treated. The heat treatment involves solution heat treatment at 960°C for 1 hour followed by quenching in warm water at 60°C. After this stage, some of the samples undergo natural ageing for 24 hours, while others were further artificially aged to 480°C with varying soaking times of 2, 4, 6 and 8 hours followed by air cooling. Wear test was conducted at varying loads of 4N and 8N, linear speed of 13.12 cm/s and a dwell time of 30 minutes. The result showed that an increase in ageing time leads to a decrease in wear rate of the alloy for both loads. Also, the samples that were further artificially aged had more wear resistant than the naturally aged samples due to formation of precipitates which are homogenous with the matrix. The minimum wear rates of 0.0114 mm³/N/m and 0.0152 mm³/N/m was obtained at 4 and 8N loads respectively. Therefore, it was established that natural and artificial ageing combined can be employed to enhance the wear resistance of Ti-6Al-4V alloy for use in biomedical applications.

1.0 Introduction

A biomaterial is any substance other than drugs or combination of substances which are synthetic or natural in origin that can be used for any period of time wholly or as a part of a system which treats, augments or replaces any tissue, organ, or function of the body (Abdulwahab *et al.*, 2015; Anupam, 2011; Callister and David, 2014). Ceramics, metals, alloys, polymers and composite materials can be used as biomaterials because of individual properties they possess, such as tensile modulus, yield strength, compression strength, ultimate tensile strength, corrosion resistance, toughness and density (Correa et al, 2009; Diomidis *et al.*, 2012; Flake, 2008; Flake, 2012). They are adapted for medical applications and thus, comprise of a whole part of a living structure. Biomaterials find daily applications in surgery, dental care and drug delivery. A construct with impregnated pharmaceutical can be placed into the body, which permits the prolonged release of drug over an extended period of time. Biocompatibility is the ability of a material to perform with an appropriate host response in a specific application (Flake, 2010).

A good biomaterial must be compatible with the human body and because of this critical requirement, the issue of biocompatibility if any must be completely resolved before the product is sent into the market for use. Therefore, all biomaterials should be subjected to standard procedures and checked for the critical requirement before they are sent into the market for use (Hendra *et al.*, 2011; Hermawan *et al.*, 2008). Wear and corrosion have been reported to be the primary reasons for the failure of implant elements (Hosam *et al*., 2017). The wear of biomaterials is a surface failure, such as abrasion and erosion, resulting from dynamic contact between two surfaces. For metallic biomaterials, wear is a major factor in controlling and determining its long-term clinical performance (Kevin, 2015). Biomaterials' wear occurs specifically due to the removal and deformation of a material's surface as a result of mechanical action of the opposite surface (Lee *et al*., 2009).

Titanium is one of the non-ferrous metals and it has about 60% of the density of steel (Li, 2013; Mariano *et al*., 2009). Titanium and its alloys have proven to be effective over the years in marine, aerospace, medicine, automobiles, missiles and energy industries (Mathew, 2000). The high strength, low weight ratio and outstanding corrosion resistance which are natural in titanium and its alloy have brought about a wide range of successful applications in various industries (Mavrogenis *et al*., 2009). Although titanium and its alloys have been in use over the years as implants, they have been found to degrade after a period of time due to wear (Mohammed *et al*., 2015; Mutlu and Christoph, 2012). Ti-6Al-4V has been in use as dental implants till date because of its favourable mechanical properties but wears off over a period of time in the oral cavity (Nikolopoulou, 2006). Many researchers have tried to find a possible solution to the wear-off of Ti-6Al-4V alloy as implant in the body as reported by Nitesh and Pivash (2012), but none have considered mitigating the wear failure of Ti-6Al-4V dental biomedical implant using natural and artificial ageing.

2. Materials and Method

2.1 Materials and equipment

The material used in this research is titanium alloy (Ti-6Al-4V) sourced from the Department of Chemical and Metallurgical Engineering, Tshwane University of Technology, Pretoria, South Africa. The equipment used include heat treatment furnace, weighing balance, hack saw, tribometer (wear test machine) and optical microscope. A Muffle electrical resistance furnace of capacity 1200°C was used for the heat treatment process. A tribometer)., weighing balance, hack saw, ball on disc tribometer from Shell laboratory in Ahmadu Bello University, Zaria-Nigeria of version 6.1.19 used for wear rate determination and a stereo microscope used for microstructural analysis.

2.2 Sample Preparation

The Ti-6Al-4V alloy with chemical composition as shown in Table 1 was sectioned under flowing cooling solutions to 1.4mm×1.4mm×0.3mm in accordance with Popoola et al., (2012) using a hack saw. The samples were then degreased, cleaned and properly dried.

Table 1: Chemical Composition of the As-received Ti-6Al-4V Alloy

Ti	Al	V	C	Fe	O	N	H
89.62	6.1	4.0	0.004	0.160	0.106	0.008	0.002

2.3 Heat Treatment of Sample

A total of 10 samples were charged into the furnace for the heat treatment which comprise of solution heat treatment (SHT) at 960°C for1hr. This was followed by careful monitoring of the temperature to ensure that it does not exceed the beta transus line of 1000°C which will cause a different phase transformation. Quenching in warm water (60°C) was done, followed by natural and artificial ageing operations. Natural ageing was carried out on two samples at room temperature for 24hrs which represent the control samples. The remaining 8 samples were further artificially aged to 480°C for varying ageing times of 2, 4, 6 and 8 hours respectively and cooled in open air. The samples were then manually ground using different grade of silicon carbide abrasive papers and mechanically polished. Figure 1 shows the heat treatment cycle used.

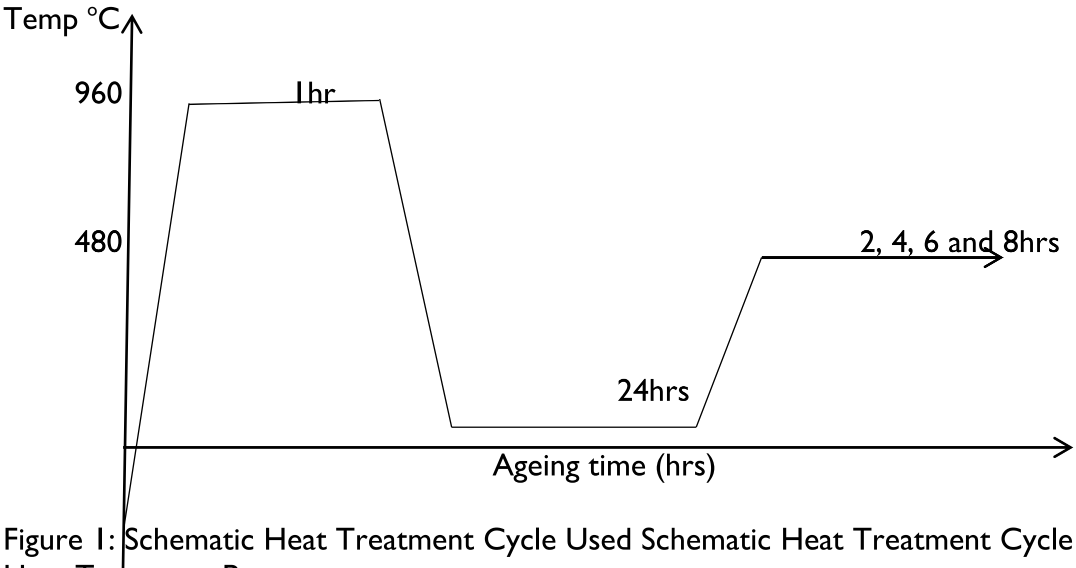

Figure 1: Schematic Heat Treatment Cycle Used Schematic Heat Treatment Cycle Used for the Heat Treatment Process

2.4 Wear Test

The wear rate of the material was carried out on the surface of the coupons using a tribometer with a ruby ball as the abrasive medium. An applied load of 4N and 8N at a linear speed of 13.12 cm/s and a dwell time of 30 minutes was used. The mass loss for each sample was determined by finding the difference between the initial and final mass to generate the wear rate.

2.5 Worn Surface Examination

The surfaces of the samples were ground using different grade of silicon carbide abrasive papers ranging from 320 to 1200 microns and polished mechanically to remove the oxide film that was formed on the surface in order to obtain a smooth on which wear test will be carried out. The surfaces of the samples were ground using different grades of silicon carbide abrasive papers ranging from 320 to 1200 microns and polished using one-micron size alumina polishing powder suspended in distilled water. The samples were placed on the stage and observed under the microscope. This was done using optical microscope (OPM) to determine the extent to which the surface integrity of the alloy was affected.

3. Results and Discussion

3.1 Wear Rate of Samples Using Ageing Treatments

The effect of increasing load of 4N and 8N on the abrasive wear is demonstrated in Figure 2. The control samples showed a wear rate of 0.0166 $mm^3/N/m$ and 0.027 $mm^3/N/m$ at applied loads of 4N and 8N respectively. Also, for samples that were artificially aged, wear rate decreases with increasing ageing time that is 0.0147 $mm^3/N/m$ to 0.0114 $mm^3/N/m$ for ageing times of 2 to 8 hours.

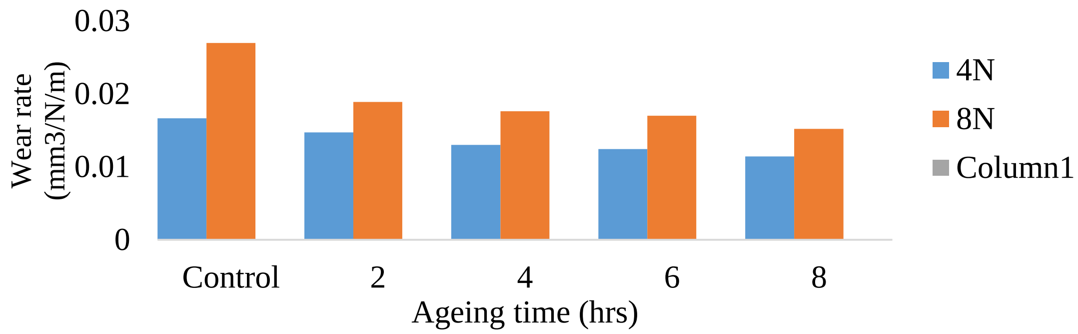

Figure 2: Variations of wear rate against ageing time for both the control and heat-treated titanium alloys

This decrease in wear rate may be attributed to the fact that at the ageing time of 2 to 8 hours, the β-phase precipitation increases with the increasing ageing time which leads to strengthening and hardening thereby causing a reduction in wear rate (Popoola *et al*., 2012). The highest wear rate for the artificially aged samples were observed at 2 hours of ageing time and the lowest at 8 hours ageing time. This may be attributed to the fact that at shorter soaking time of 2 hours, the precipitation of β-phase may not have taken place hence the material is said to be under aged (Reza and Gholam, 2011).

For samples that were artificially aged, wear rate decreases with increasing ageing time that is from 0.0189 $mm^3/N/m$ at 2 hours of ageing to 0.0152 $mm^3/N/m$ at 8 hours ageing. This decrease in wear rate may be attributed to the β-phase precipitate which increases with increasing ageing time, thereby causing strengthening and hardening of the alloy hence a reduction in wear rate (Roth *et al*., 2010; Schwarz *et al*., 2009; Wang *et al*., 2011).

3.2 Worn Surface Analysis

The optical micrographs of the worn-out samples shown in Figure 3 indicate the degree of wear by the presence of deep scratches and delamination of material from the surface. This worn debris and delamination decrease as the soaking time increases from 2 to 8 hours.

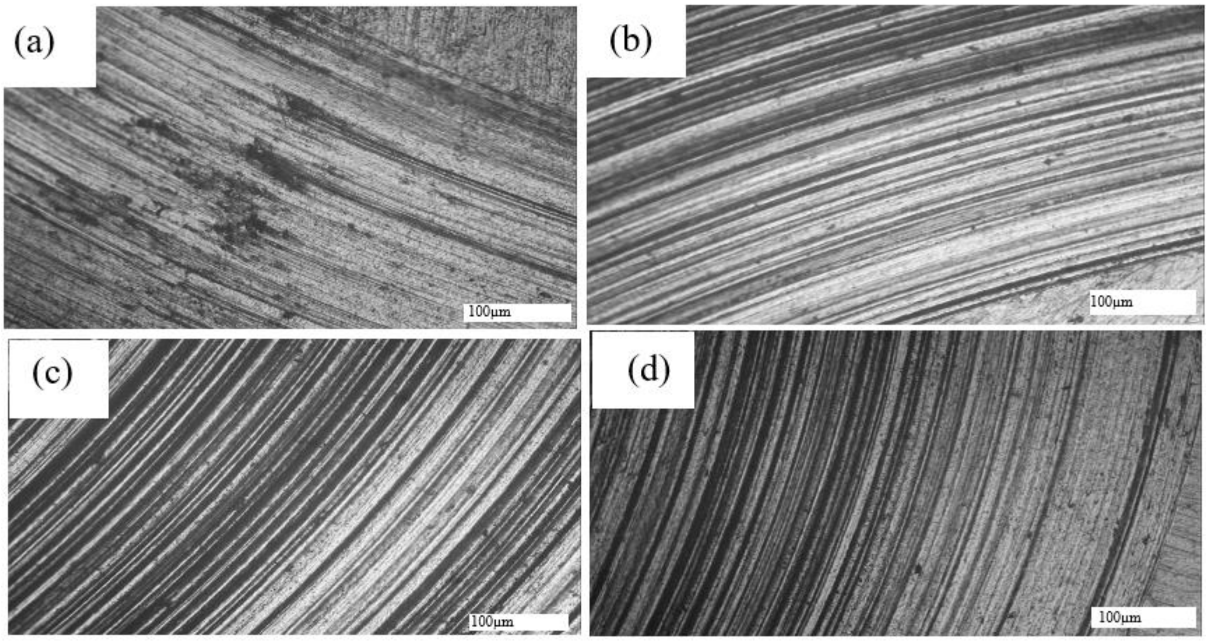

Plate 3: Optical micrographs of the abrasive worn-out samples of Ti-6Al-4V alloy artificially aged at 480°C and soaked for (a) 2hrs (b) 4hrs (c) 6hrs and (d) 8hrs

4. Conclusion

From the analysis above, it can be concluded that increasing the ageing time reduces the wear rate of the alloy under investigation. Also, artificially aged samples have better wear resistance than samples that were naturally aged and samples artificially aged at 8 hours of soaking time showed the maximum resistance to abrasive wear. Finally, the best wear resistance of the Ti-6Al-4V alloy is at 4N load application.

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