Corrosion Resistance of Ti-6Al-4V Alloy Finished by An Advanced ELID Grinding System

Masayoshi MIZUTANI[1], Jun KOMOTORI[1], Kazutoshi KATAHIRA[2], Hitoshi OHMORI[2]

[1] Department of Mechanical Engineering, Keio University, 3-14-1, Hiyoshi, Kohoku-ku, Yokohama-city, Kanagawa 223-8522, JAPAN

[2] Materials Fabrication Laboratory, RIKEN (The institute of Physical and Chemical Research), 2-1, Hirosawa, Wakou-city, Saitama 351-0198, JAPAN

ABSTRACT

Metallic biomaterials, such as titanium alloys and stainless steels, require enhanced chemical stability, which is dependent on the quality and thickness of the oxide layer on a material surface. Therefore, if we can form a thick and stable oxide layer during machining, it is very effective in improving the surface properties. This will also help us to skip other surface treatment and allow for significant saving in energy and procedure. The author previously proposed a new ELID grinding system, in which a direct current of extremely short pulses are applied to the workpiece being ground. In this study, to ensure the fabrication of a surface with desirable characteristics for biomaterials, three types of specimens, which were processed with different surface finishing methods were prepared. The processed surfaces were analyzed by performing ultimate analysis using an Energy Dispersive X-ray analyzer (EDX). To measure the thickness of surface oxide layers, detailed observations were performed by using an X-ray Photoelectron Spectroscopy (XPS). In order to investigate corrosion resistance, electrochemical corrosion tests were carried out using a three electrode electrochemical cell connected to a computer driven potentiostat. EDX and XPS analysis indicated a significantly thicker oxide layer for surfaces modified by the proposed technique. The results of corrosion resistance testing suggest that surfaces finished using this technique inhibit a pitting of the surface and prevents dissolution of metal-ions because of the thick oxide layer. Consequently, the proposed technique improves chemical properties compared to those of polished and conventional ELID ground surface.

1 INTRODUCTION

Biomaterials require certain desirable properties, which include high corrosion, wear and fatigue properties [1] [2]. Especially, in the case of very small bio-components, such as a medical microsystem, it is very difficult to apply the conventional surface modification process, such as PVD. Therefore, it is important to develop a new surface modification process for micro scale biomaterials.

The authors previously proposed that an ELID (Electrolytic in-process dressing) grinding method [3] [4] could form a thick oxide layer on the ground surface during the machining process and improve corrosion resistance [5] [6]. However, in order to apply the ELID grinding technique as a method of surface modification for biomaterials, it is necessary to achieve further improvement of corrosion resistance.

The aims of the present study are to develop an advanced ELID grinding system for surface modification of biomaterials, and to clarify the effects of this newly developed technique on the corrosion resistance of ground surfaces.

2 BASIC PRINCIPES OF A NEW ELECTRICAL GRINDING SYSTEM

Figure 1 shows a schematic illustration of electrochemical reaction during the grinding process; the upper figure represents chemical reaction between electrode and grinding wheel, and the lower represents reaction between grinding wheel and specimen. In this system, an electrode about 1/6 the area of the entire grinding wheel

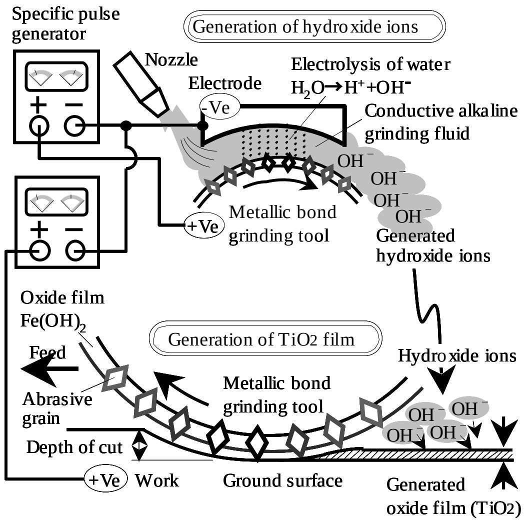

Fig. 1 Schematic illustration of a new ELID grinding system

surface is set above a conducting metallic bond grinding wheel with a gap of about 0.3 mm. Positive potential is applied to the grinding wheel and negative potential to the electrode by using a specific pulse generator (upper figure). During machining, the potential electrolyte decomposes the conductive alkaline machining fluid, thereby generating OH^- ions. At the same time, since positive potential is applied by a different circuit to the specimen, free OH^- ions in the machining fluid are attracted to the work surface, resulting in the occurrence of an anodic oxidation reaction (lower figure).

3 RESULTS AND DISCUSSION

The properties of the machining surfaces were investigated by performing ultimate analysis using an Energy Dispersive X-ray Analyzer (EDX). Figure 2 shows the results. In this study, three types of specimens were compared; (1) specimen ground with the advanced ELID grinding system (Ap-ELID series), (2) specimen ground with conventional ELID grinding (ELID series), and (3) specimen polished by SiO_2 powder (Polished series). Compared with the ELID and Polished series, the Ap-ELID series exhibited a clearly higher concentration of oxygen atoms. This suggests that the thickness of an oxide layer increases by the advanced ELID grinding system.

In order to investigate the differences of the thickness of the oxide layer formed on the finished surfaces, titanium and oxygen profiles in the depth direction were measured by using an X-ray Photoelectron Spectroscopy (XPS). Figure 3 shows the

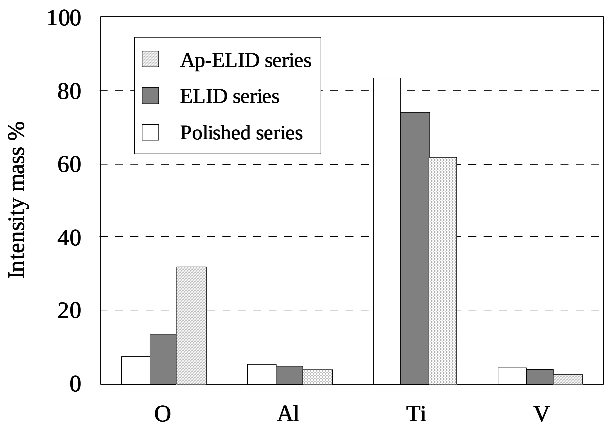

Fig. 2 Ultimate analysis of the surface

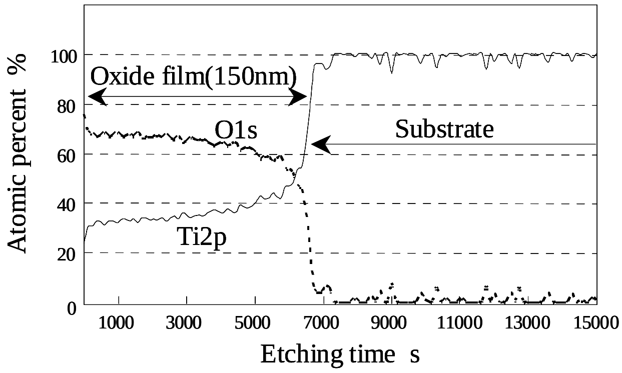

Fig. 3 Titanium and oxygen profile in the depth direction of the Ap-ELID series

results. The thickness of the oxide layer formed on the surface of the ELID series was about 15nm, and that of the Polished series was about 3nm [3]. For comparison, the newly developed ELID grinding system can form a very thick oxide layer of about 150nm, as shown in this figure.

In order to investigate the effect of this surface modified layer on the corrosion resistance of specimens, corrosion rates of these specimens were measured by an AC impedance method. Figure 4 shows the results. The Corrosion rate of the Ap-ELID series was clearly lower than that of the ELID and Polished series. This means that

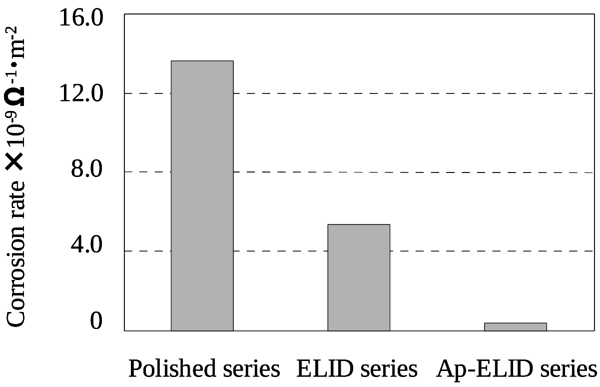

Fig. 4 Comparison of the corrosion rate

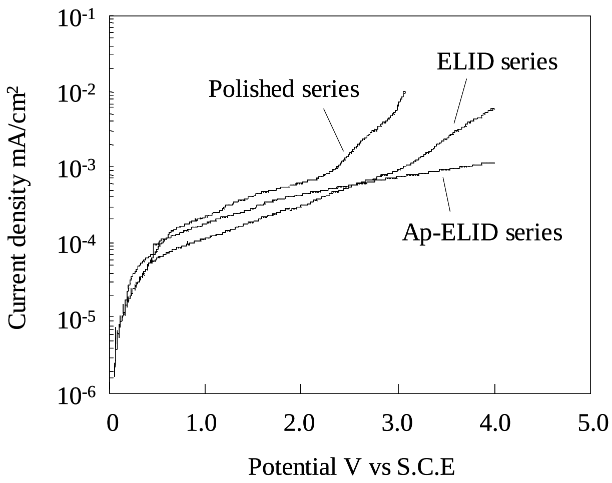

Fig. 5 Cyclic polarization curves

corrosion rate is improved by grinding a surface using the proposed technique.

Figure 5 shows the results of potentiodynamic polarization measurements. In this figure, the higher the pitting potential, the higher the corrosion resistance of the workpiece is. The pitting potential of the Polished series was about 2.5V, and that of the ELID series was 3.0V. In the case of the Ap-ELID series, however, no rapid increase of current density was observed and a pitting potential was not found. This suggests that the Ap-ELID series inhibits a pitting of surface and prevents dissolution of metal-ions because of a thick oxide layer.

4 CONCLUSION

This paper presents an advanced ELID grinding system which can form a thick and stable oxide layer on processed surface by applying extremely short direct current pulses during grinding. The author focused on developing a new ELID grinding system for surface modification of biomaterials, and clarifying the effects of a newly developed technique on the corrosion resistance of ground surfaces.

EDX and XPS analysis indicated a significantly thicker oxide layer for surfaces modified by the newly technique. This modified layer inhibits a pitting of surface and improves corrosion resistance. This suggests that this ELID grinding system can be used to fabricate machined surfaces with desirable characteristics for biomaterials including micro-tools which surfaces cannot easily be modified after machining.

REFERENCES

[1] Winter, G.D., and Leray, J.L.: Evaluation of Biomaterials, *John Wiley & Sons Ltd*, 1980.

[2] Wisbey, A., Gregson, P.J., and Peter, L.M.: Effect of Surface Treatment on the Dissolution of Titanium-based Implant Materials, *Biomaterials*, 12, 470-473.

[3] Ohmori, H., and Nakagawa, T.: Analysis of Mirror Surface Generation of Hard and Brittle Materials by ELID (Electrolytic In-Process Dressing) Grinding with Superfine Grain Metallic Bond Wheels, *Annals of the CIRP*, 44, 1, 287-290.

[4] Ohmori, H., and Nakagawa, T.: Utilization of Nonlinear Conditions in precision Grinding with ELID (Electrolytic In-Process Dressing) for Fabrication of Hard Material Components, *Annals of the CIRP*, 46, 1, 261-264.

[5] Mizutani M., Katahira K., Komotori J., Nagata J., and Ohmori H.: Surface finishing for biomaterials -Application of the ELID grinding method-, *International Journal of Modern Physics B*, 17, 1&2, 2003, 259-264.

[6] Ohmori H., Katahira K., Nagata J., Mizutani M., and Komotori J.: Improvement of Corrosion Resistance in Metallic Biomaterials by a New Electrical Grinding Technique, *Annals of the CIRP*, 51, 1, 2002, 491-494.