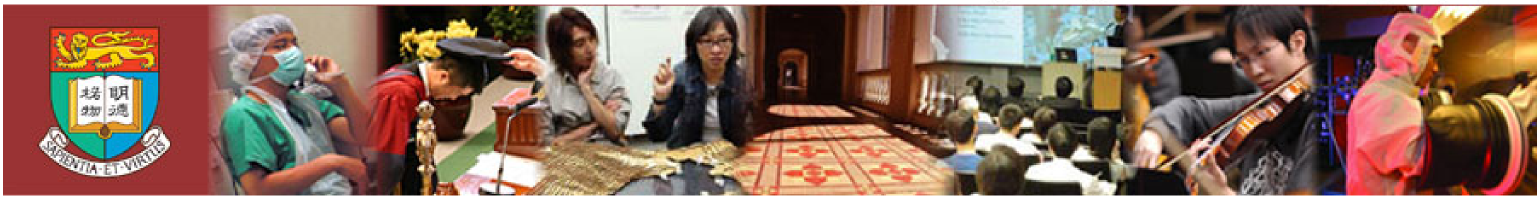

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A Novel Effect of Sandblasting on Titanium Surface –Static Charges Generation

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Abstract

Recent advances in biomaterials research suggest that electrical charges on a dental implant surface significantly improve its osseointegration to living bone, as a result of selective osteoblasts activation and fibroblasts inhibition. This study aims at investigating the possibility of using sandblasting to modify the electrical charges on the surface of titanium materials. Our experiments used Al_2O_3 grits to blast on CP2 titanium plates, for durations between 3-30 s. After sandblasting, Ti surfaces were measured for their electrostatic voltage. The results indicate a novel finding, *i.e.,* negative static charges are

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generated on the titanium surface, which may stimulate osteoblasts activity to promote osseointegration around dental implant surface. This finding may at least partially explain the good osseointegration results of sandblasted titanium dental implants, in addition to other known reasons, such as topological changes on the implant's surface. However, the static charges accumulated on the titanium surface during sandblasting decayed to a lower level with time. It remains a challenging task to seek ways to retain these charges after quantification of desired level of negative charges needed to promote osteoblasts activity for osseointegration around dental implants.

Key words: titanium dental implant, surface electrical charges, sandblasting, surface treatment.

1 Introduction

Titanium is currently the most widely used material for dental implants. One key reason for its popularity is its ability to osseointegrate with living bone. Rapid and strong osseointegration of a titanium dental implant leads to high-quality bone-to-implant contact, which, in turn, improves the implant's durability. Previous studies have shown that various properties of the titanium implant's surface, *e.g.*, roughness, chemical composition, wettability and surface charge, etc., may significantly influence the quality of the implant's osseointegration. Hence, a plethora of surface treatment methods have been studied to modify surface properties of the titanium dental implant, in order to improve its osseointegration [1, 2].

Adhesion and proliferation of osteoblasts, the cells that form new bones, on the titanium surface are essential processes for bone growth onto the implant surface. The specific mechanism of osteoblasts accumulation is once poorly understood. However, it is known that the electrostatic properties of the natural oxide layer (such as TiO_2) on titanium materials are among the most important factors that determine the accumulation of osteoblasts on the implant's surface [3]. For instance, a negative surface charge is reported in several studies to promote osteoblasts adhesion [4, 5]. Surface charge modification methods aim at altering such electrical properties of the titanium surface to promote the adhesion of osteoblasts, which strengthens and accelerates the implant's osseointegration.

Sandblasting is a simple and common technique used to create a rough microtopography on the titanium surface, which helps to accelerate the attachment of osteoblasts in a biological environment, according to various *in vitro* studies [6-11]. However, the favorable effects of sandblasting had only been assumed to be attributable to an increase in surface area and roughness on titanium dental implants. The aim of this study was to test and analyze if the surface charge modification effects of sandblasting existed. If so, this may partially explain the favorable effect of sandblasting on osseointegration and open up the possibility of enhancement of osteoblasts activity on the implant surface.

2 Materials and Methods

2.1 **Materials**

In total, 25 pieces of CP2 titanium plates with dimensions of 15 mm × 15 mm × 1 mm were machine-cut and polished for the experiments. These plates were randomly divided into 5 test groups, each containing 5 plates. All plates were cleaned with acetone, and dried in the air for 30 min before they were sandblasted.

2.2 Sandblasting

Aluminum oxide (Al_2O_3, Renfert, Hilzingen, Germany) grits were used to blast on each titanium plate with a constant air pressure of 333.54kPa. The purity of the grits was reported to be 99.6%, and their average diameter was above or equal to 110 μm as shown in Fig. 1 under SEM magnification of ×200. The blasting nozzle was set perpendicular to the surface of the titanium plate at a fixed 10 mm distance. Fig. 2(a) illustrates the sandblasting machine used in this study. Fig. 2(b) illustrates the positioning of blasting nozzle and titanium plate during sandblasting.

Each titanium plate was sandblasted for a continuous period. In each experimental group, the 5 individual titanium plates were blasted for the same duration of 3, 5, 10, 15 or 30 s, respectively. All titanium plates were insulated by rubber handling devices during sandblasting and measurement of charges. All experiments were performed in the same laboratory, under a controlled room temperature between 19^{o}C - 21^{o}C and under a relative humidity of 37- 43%. The relative humidity, temperature and the background static voltages, when carrying out our experiments for the five experimental groups are listed in Table 1.

2.3 Electric Charge Measurement

We used an electrostatic meter (IZH10, SMC Corporation, Tokyo, Japan) to measure the static electric voltage on the titanium surface immediately after sandblasting. During measurements, the distance between the grounded electrostatic meter and the titanium plate was fixed to 10 mm and parallel to the titanium plate. The reported static voltage (V) of the titanium plate was compared to the ground level. The minimum measurement unit of the meter is 10V[1]. Fig. 2(c) demonstrates the static voltage meter, which includes the main body and the detector. Fig. 2(d) illustrates the positioning of the detector and sandblasted titanium plate during static voltage measurement.

Immediately after finishing sandblasting of the titanium plate (which is considered time = 0), it was moved out of the blasting chamber by hand with a thick rubber glove and static voltage measurement was started. Because the procedure of manually moving the titanium plate takes some time (<10 s), we report the first measurement at the 10th second after the sandblasting was finished. After that, we measured the electrostatic voltage on every titanium plate in every 10 seconds until the 120th second, *i.e.* the other 11 measurements were taken at 20, 30, 40, 50, 60, 70, 80, 90, 100, 110 and 120 s after sandblasting.

2.4 Photographs and SEM Images of Ti Plates

Fig. 3 (a) shows a randomly selected titanium specimen which was cleaned and dried before sandblasting. The purpose of these photographs is to demonstrate visually the roughened surface area by sandblasting in groups 1 to 5.

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[1] The static voltage meter used in our experiments report voltage values in the unit of kV. The meter's precision is limited to 2 digits after the decimal point, *i.e.* 0.01kV=10V.

The change in titanium topography after sandblasting was further examined using a scanning electron microscope. All SEM images used the same magnification of ×2000.

2.5 Statistical analysis

The mean value, standard deviation (SD) and coefficient of variation (CV) were calculated from the 5 replicate measurements for all time intervals in all 5 titanium groups. All calculations were carried out using Excel 2007 software (Microsoft, USA).

3 Results

3.1 Static Charges

Immediately after sandblasting, we observed a negative static voltage that was significantly higher than that of the environment on every titanium plate. This voltage, however, decreases with time. Fig. 4 plots the values of mean and standard deviation (shown as vertical lines) of the static voltages of all five experimental groups.

It seems that regardless of the sandblasting duration, the mean voltage always reaches the highest value of its own experimental group at the first instance, and decreases after that. After 40 to 50 s, the decrease in the voltage values levels off.

3.2 Topographical Features

Figs. 3 (b)-(f) show the photographs of the 5 sandblasted titanium plates randomly selected from groups 1-5. Darker areas in the images are the blasted areas with significantly higher microscopic roughness than the brighter areas. After sandblasting for 3 s, the surface of titanium plate from group 1 was only partially roughened. As the blasting duration time increases, the roughened area on the titanium plate expanded. Hence, the darker area on the surface of the plate from group 2 (blasted for 5 s each) is slightly larger compared to plate from group 1 (blasted for 3 s). The proportion of darker area increased with increased duration of blasting. For the plate in the fifth group, almost the entire surface of the blasted side was roughened.

Figs. 5(a)-(f) display the SEM images of the roughened surface areas of the six titanium plates with a magnification of $\times 2000$, corresponding to the photographs in Figs. 3(a)-(f), *i. e.* the image in Fig. 5(a) is of a titanium plate before sandblasting, Figs. 5(b)-(f) correspond to the five selected titanium plates (from groups 1 to 5) after sandblasting. From these images, no significant difference in their roughness at the microscopic level is observed.

3.3 Statistical Analysis

Table 2 shows the mean values, SDs and CVs of static voltages for every titanium group at each time interval. The 4th group (blasted for 15 s) is the only group which has all the CV values under 20%, while the remaining 4 groups each has one or more CV value(s) exceeding 20%. This indicates that the data distribution of the 4th group has the smallest dispersion.

4 Discussion

In all experiments, we measured the electric voltage on the titanium surface, rather than the amount of static charge directly. This is because the amount of charge can be calculated directly from the voltage reading. The value of V is proportional to the amount of charge q, *i. e.* $q=C\cdot V$ where C is a constant representing the capacitance of the conductor material. The voltage is also proportional to the distance between the titanium plate and the detector of the electrostatic meter [12]. Therefore, provided that the capacitance of titanium and the distance between the detector and titanium surface are stable, change in the electric voltage (rapidly decreases in our experiments) reflect changes in charge on each titanium plate.

Titanium is electrically conductive, whose electrical conductivity is 3% International Annealed Copper Standard (IACS) [2] [13]. Therefore, when charges accumulate on the titanium plate's surface, the distribution of the charges satisfies that the field strength is zero at any point inside the plate. Static charge can only locate on the surface of the titanium plate. Fig. 6 illustrates the electric field around each titanium plate, which is perpendicular to its surface. Charge accumulation is assumed to be the strongest around the sharper points of the plate [12]. In practice, the titanium dental implant usually takes the form of a screw and thread. This may imply that electric charges tend to accumulate on the sharp edges of the screw threads.

When measuring the voltage on a titanium plate, the distance between the detector of the static voltmeter and the plate was fixed to be 10 mm, instead of 50 mm suggested by the user's manual. At a 50 mm distance (i.e., five times larger than the distance used in our experiments), the measured static voltage readings are much lower which often drop below the minimum reading of the meter and are severely influenced by the static

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[2] IACS is a unit of electrical conductivity for metals and alloys relative to a standard annealed copper conductor. 100% IACS referring to a conductivity of 5.80×10^7 siemens per meter at 20^{o}C [14].

voltage caused by atmospheric charges. In our preliminary studies, we found that 10 mm was a more suitable distance for our experiments.

After sandblasting, no significant difference in the roughness at the microscopic level of the sandblasted surface area on titanium plates was found. One possible reason is that during sandblasting, the nozzle was moving at a certain controlled, slow speed to cover all surface area of a titanium plate. Hence, although the total blasting time was different among the five experimental groups, each part of the blasted area was blasted for roughly the same time duration.

In statistical analysis, mean values are used to show the change in static voltage with time for each titanium group after sandblasting, and also to compare the voltages between different groups. SDs and CVs are used to show the dispersion of the data from each group. The values of CV of the static voltage are rather high for most experimental groups. The main reason may be that there are several factors affecting the detected static voltage, including environmental relative humidity, contact area, surface contamination, and electrical spark of the air. Among these, humidity seems to play a significant role in the electric discharge. In general, high atmospheric humidity leads to reduced amount of static charge on a surface [15]. Another factor that may affect data distribution is the manual control of the sandblasting device. Ideally, the sandblasting process of the 5 plates from all groups should be performed in exactly the same way. In practice, however, there are often slight variations. The shorter the sandblasting time, the harder it is to control the sandblasting procedure precisely. Data from the 4th group (blasted for 15 s) shows lower CV values than those from groups 1-3 (blasted for 3, 5 and 10 s respectively). However, the distribution of data from the 5th group, which are blasted for 30 s, is wider than that that of the 4th group.

A longer blasting time causes more contacts between titanium surface and the blasting material. Accordingly, when the experimental environment remains unchanged, longer blasting duration should lead, in principle, to more charge on titanium surface. However, the results do not show a clear relationship between blasting duration and the amount of accumulated charge. This may be further complicated by fluctuations in the humidity in the laboratory over a longer period of time.

Before any experiments, we measured zero background electric voltage in our laboratory. After a few sets of experiments, however, this background voltage gradually increases to the level of -20 V to -50 V, and stabilizes within this range. Consequently, the minimum reading on the electrostatic meter for all subsequent experiments is not zero but the background voltage level.

The experimental results suggest that the negative charge accumulated on the titanium surface due to Al_2O_3-blasting decays rather fast into the environment. Maintaining such charges on the titanium dental implant appears to be a challenging but promising way to improve the implant's osseointegration. Bearing in mind some other applications of Ti in dentistry, such as the fabrication of crowns and bridges and their related cementation, it is interesting to understand if the proven promotion of adhesion by silane coupling agents [16] alone [17] or blended with a non-functional cross-linked silane [18, 19] to silica-coated Ti [20, 21] may be promoted further by sandblasting.

5 Conclusion

This preliminary study reveals that sandblasting is a simple and effective way to increase the static electric charges on the surface of titanium. This phenomenon may partially explain the good osseointegration properties of Al_2O_3-blasted titanium, in addition to the topographical changes on the titanium surface caused by sandblasting. The results confirm that Al_2O_3 blasting gives a negative charge to titanium materials. These static charges gradually decay into the environment until reaching a stable voltage that is equal to the electrostatic voltage of the environment.

6 Acknowledgements

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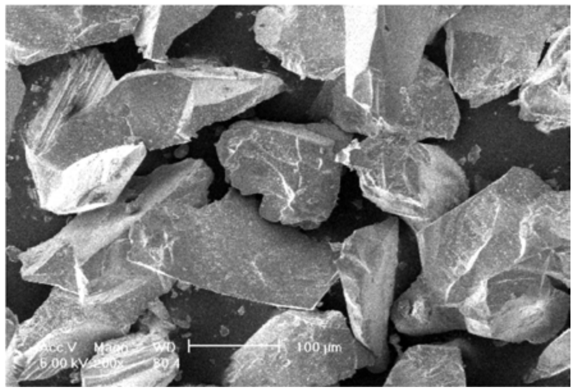


Fig. 1 SEM micrographs of Al_2O_3 grits with 110µm diameter, magnification×200

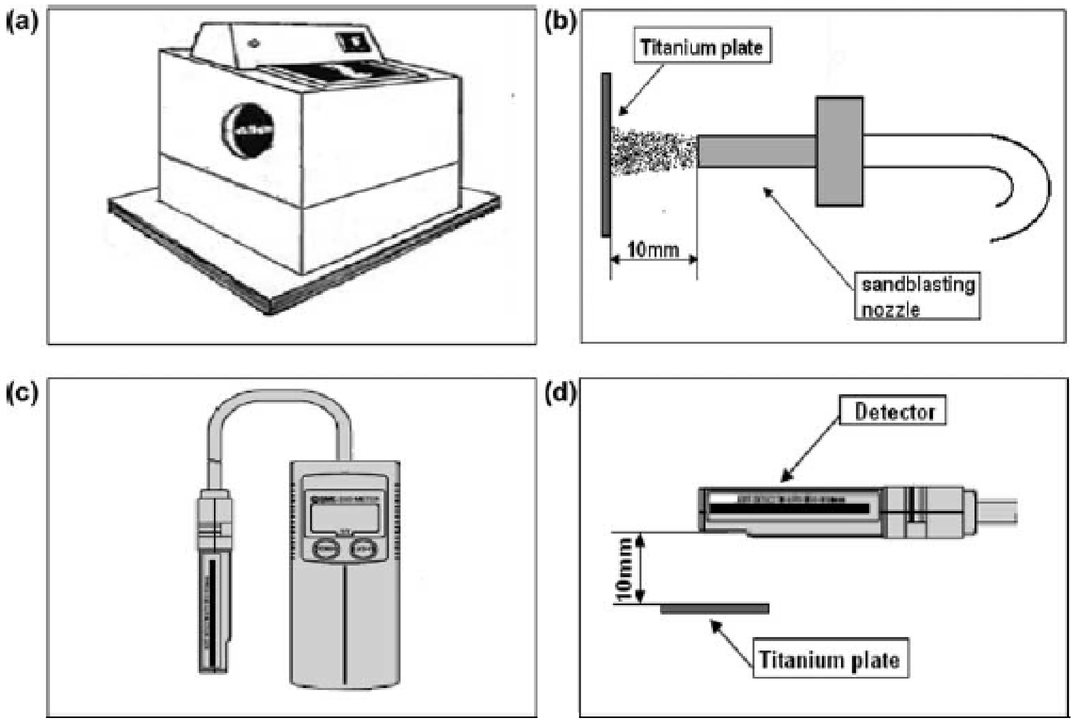


Fig. 2 Schematic diagrams of (a) main body of sandblasting machine used in this study (b) positioning of the blasting nozzle and the titanium plate during sandblasting (c) electrostatic meter including main body and detector (d) positioning of the electrostatic meter's detector and the sandblasted titanium plate during static voltage measurement

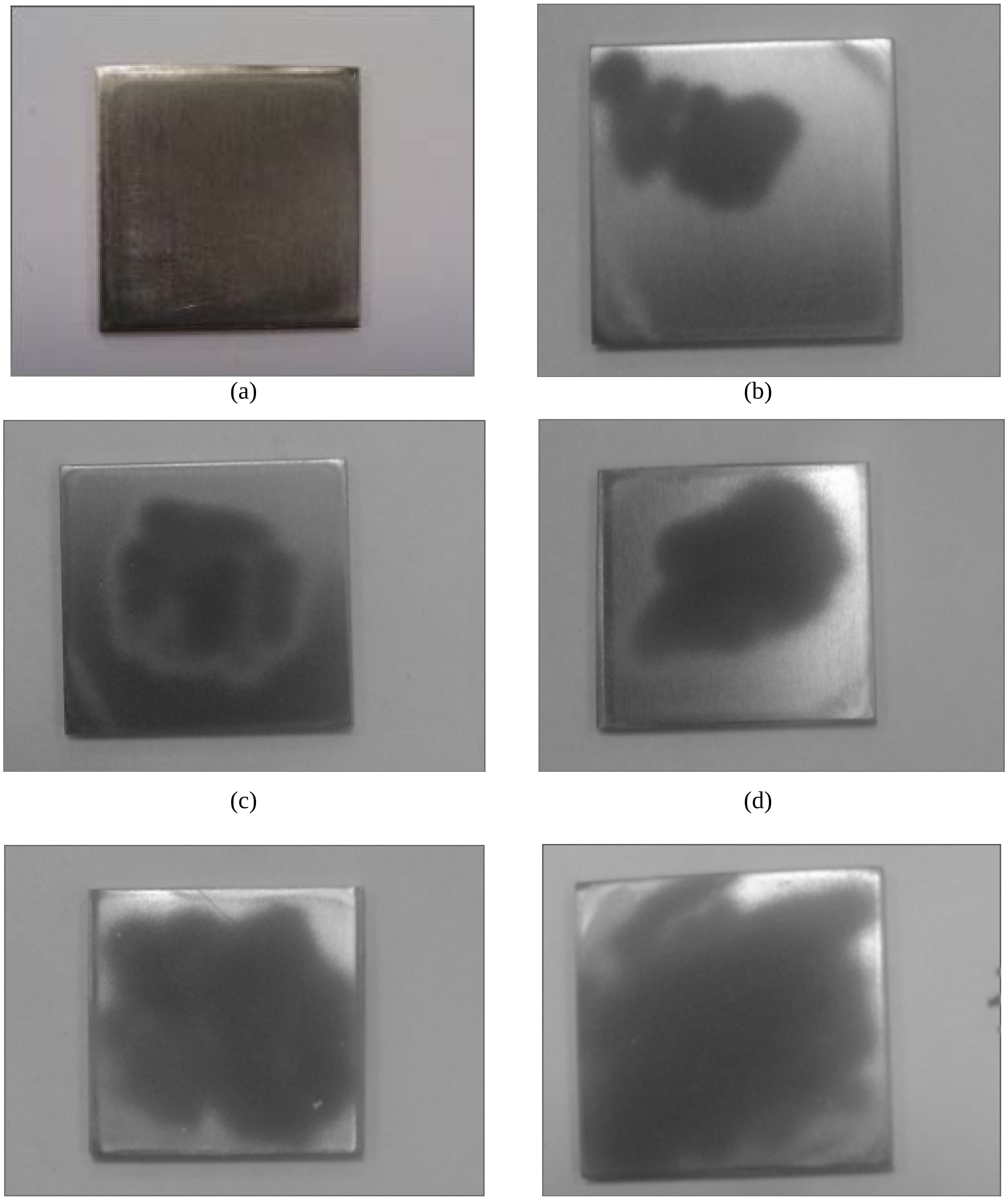
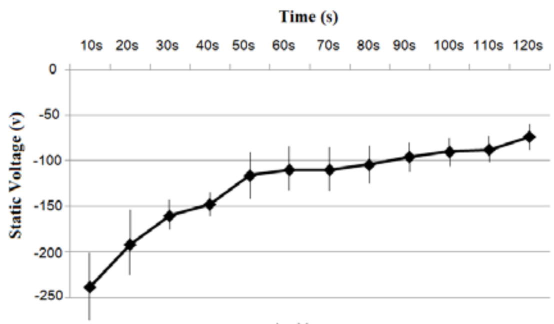
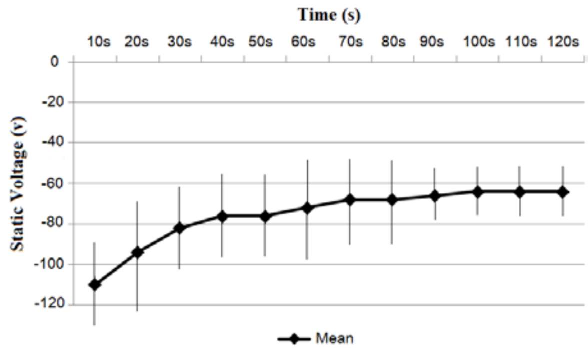


Fig. 3 Photographs of titanium plates before and after sandblasting. (a) A titanium plate before sandblasting. (b)-(f) Titanium plates after 3, 5, 10, 15 and 30 seconds of sandblasting, respectively. The size of each titanium plate is 15mm×15mm×1mm.



(a)



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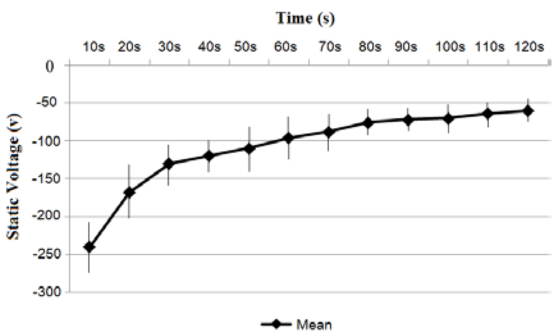

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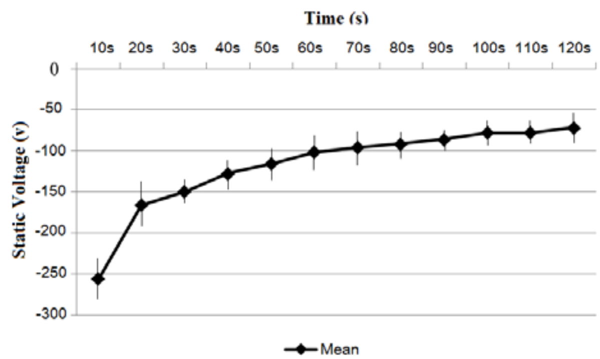

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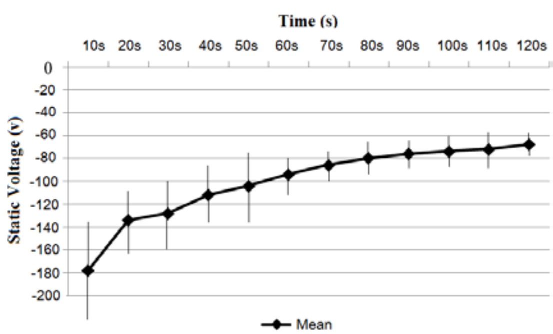


(e)

Fig. 4 Static voltage on CP2 Ti surface versus time after sandblasting by Al_2O_3, x-axis represents time after sandblasting, y-axis is the static voltage on titanium surface, and vertical lines show the standard deviations of the replicate measurements. (a)-(e) Titanium plates sandblasted for 3, 5, 10, 15 and 30 seconds, respectively.

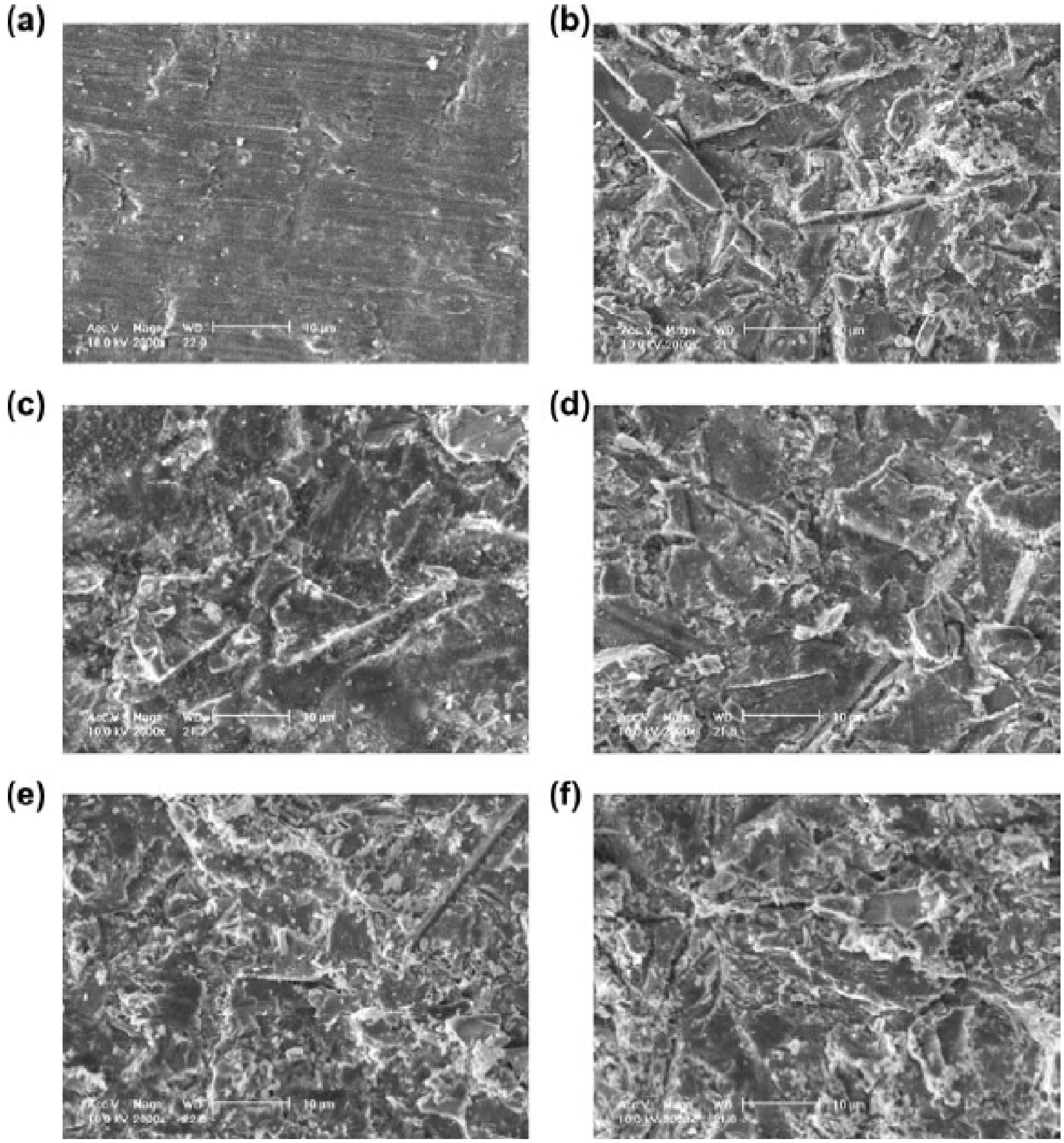
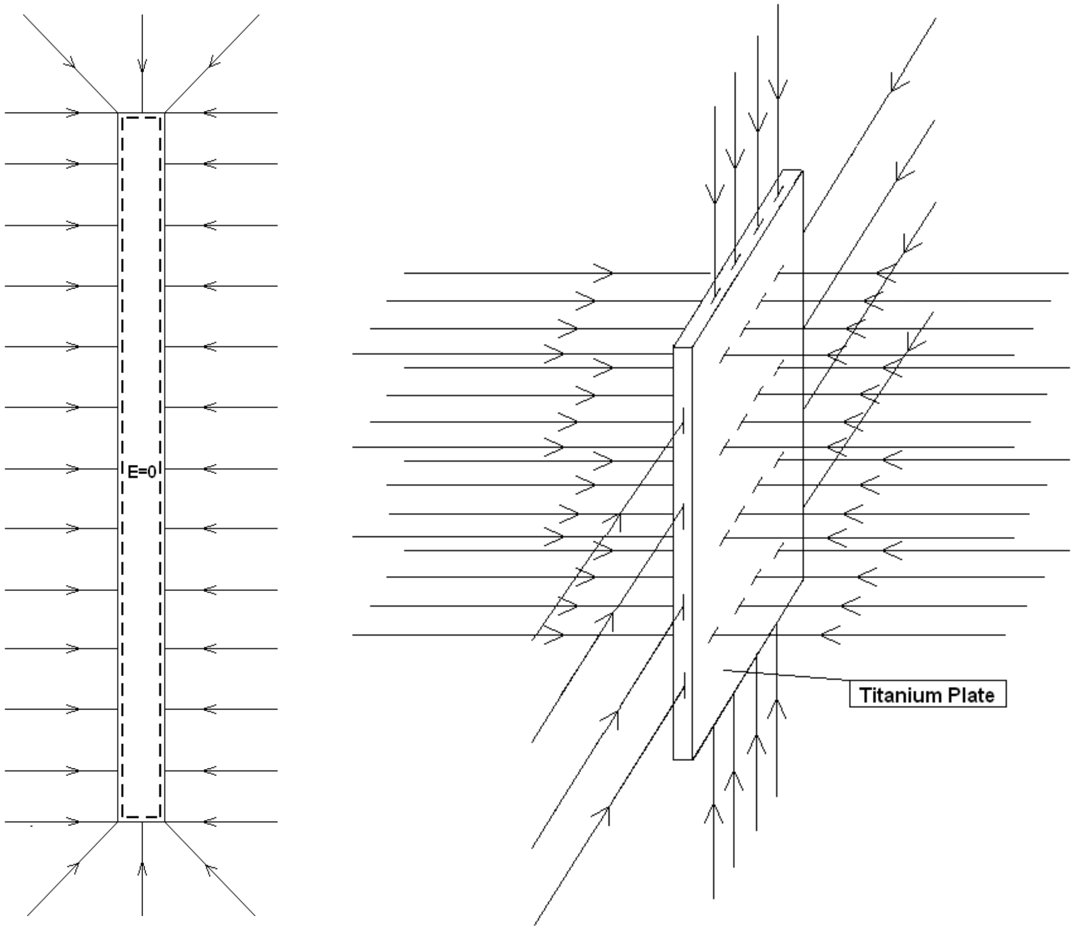


Fig. 5 SEM images with ×2000 magnification of titanium plates before and after sandblasting. (a) A titanium plate before sandblasting. (b)-(f) Titanium plates after 3, 5, 10, 15 and 30 seconds of sandblasting, respectively.



(a) (b)

Fig. 6 A schematic presentation of (a) Cross-section of negatively charged titanium plate (b) Electric field of negatively charged titanium plate. Every point inside the titanium plate has an electric field E of zero strength. Static charge only appears on the surface of the titanium plate.

Table 1 Mean static voltages, humidity and temperature of the environment during sandblasting experiments

Sandblasting duration	**3s**	**5s**	**10s**	**15s**	**30s**
Mean Background Static Voltage (V)	–48	–34	–28	–36	–32
Humidity (%)	36	43	37	37	43
Temperature (^{o}C)	19	19	21	21	19

Table 2 Means, standard deviations and coefficients of variation of static voltages of titanium plates after sandblasting

Time after Sandblasting	3s			5s			10s			15s			30s		
	Mean (V)	SD (V)	CV (%)	Mean (V)	SD (V)	CV (%)	Mean (V)	SD (V)	CV (%)	Mean (V)	SD (V)	CV (%)	Mean (V)	SD (V)	CV (%)
10s	–238	35.6	15.0	–110	26.5	24.1	–240	35.4	14.8	–256	27.0	10.5	–178	39.6	22.2
20s	–192	36.3	18.9	–94	31.3	33.3	–168	32.7	19.5	–166	20.7	12.5	–134	28.8	21.5
30s	–160	15.8	9.9	–82	19.2	23.4	–130	25.5	19.6	–150	10.0	6.7	–128	28.6	22.3
40s	–148	11.0	7.4	–76	20.7	27.2	–120	17.3	14.4	–128	14.8	11.6	–112	25.9	23.1
50s	–116	26.1	22.5	–76	20.7	27.2	–110	26.5	24.1	–116	15.2	13.1	–104	25.1	24.1
60s	–110	22.4	20.4	–72	21.7	30.1	–96	24.1	25.1	–102	13.0	12.7	–94	15.2	16.2
70s	–110	22.4	20.4	–68	19.2	28.2	–88	21.7	24.7	–96	15.2	15.8	–86	16.7	19.4
80s	–104	18.2	17.5	–68	19.2	28.2	–76	16.7	22.0	–92	11.0	12.0	–80	15.8	19.8
90s	–96	13.4	14.0	–66	15.2	23.0	–72	16.4	22.8	–86	5.5	6.4	–76	11.4	15.0
100s	–90	14.1	15.7	–64	11.4	17.8	–70	18.7	26.7	–78	8.4	10.8	–74	13.4	18.1
110s	–88	16.4	18.6	–64	11.4	17.8	–64	16.7	26.1	–78	8.4	10.8	–72	16.4	22.8
120s	–74	16.7	22.6	–64	11.4	17.8	–60	12.2	20.3	–72	13.0	18.1	–68	13.0	19.1