International Journal of Engineering & Technology, 7 (4.39) (2018) 14-17

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Design and Development of Small Chamber-Type Low-pressure Plasma Surface Treatment Equipment to Improve the Shear Bond Strength of Materials for Dental Prostheses

Byung-Kwon Moon[1], Kyoung-Tag Ko[2], Jong-Tak Lee[3], Min-Kyung Ji[4], Jun-Ho Bang[5], In-Ho Ryu[*6]

[1]Department of IT Applied System Engineering, Engineering Departments, Chonbuk national University, Korea
[2]Department of Engineering, Research Institute, Poly Biotech. co., Ltd, Korea
[3]Department of Prosthodontics, School of Dentistry, Chonnam National University, Korea
**Corresponding author E-mail: toto00@jbnu.ac.kr*

Abstract

Background/Objectives: This study was to design a small chamber-type equipment by investigating the influence of dental prostheses treatment on the shear bond strength.
Methods/Statistical analysis: The equipment was designed for the requirement of dental prostheses surface treatment. Two groups of zirconia disks were treated with low-pressure plasma (LP) by the prepared equipment (13.7 mA, 625V, 8.6W and minimum vacuum degree) and atmospheric plasma jet (AP), individually. In addition, untreated disks were regarded as the control. One-way ANOVA analysis was used to compare different surface treating groups.
Findings: The output of power supply graph indicated the equipment was obtained the steady power(48kHz). On comparison, it existed a statistically significant different between the LP group and the control group ($p<0.05$). However, the results of the LP group and AP group were similar. Among the all, the highest shear bone strength value was found in the LP group (8.50±2.87MPa) and the lowest in the control group (5.57±3.28MPa). The low-pressure plasma surface treatment seems to have a better ability than other types of surface treatment (atmospheric plasma jet, etc.). Moreover, it is expected to be utilized in treating the surface of dental prostheses with plasma.
Improvements/Applications: This LP surface treatment equipment for dental prostheses was found to function better than other surface treatment equipments. It is optimal to develop in the dental prostheses modified field.

Keywords: *low-pressure plasma, surface treatment, equipment, dental prostheses, Shear bond strength.*

1. Introduction

Plasma is a high-density ionized gas which ions and electrons equally share due to free electrons from which gas atoms or molecules are supplied with electric energy [1]. Since a very high temperature (hundreds of degrees Celsius) and a giant-size generator are required to generate plasma, it has been used in limited cases in medical fields. Recently, studies have been conducted on the generation of low-pressure plasma at room temperature (~27℃) at around 300K [2].
Various types of low-pressure plasma generators have been actively researched, including pen types (nanosecond pulsed plasma), injection needle types (RF plasma; radio frequency, microwave pulsed plasma), brush types (DC plasma; direct current), and jet types or large-area types (DBD; dielectric barrier discharge) [3]. Plasma can be used in dental medicine in two main application areas. First, oral tissues can be directly treated with plasma, and second, plasma can also be used to sterilize the surface of dental equipment and materials, or to modify the surface of dental materials [4]. Plasma applied to dental materials changes the oxidized layer of the surface of the materials due to the chemical composition of process gases without causing any change in the form of the surface, which results in chemical changes such as hydrophilicity [5]. Studies on the surface modification of dental materials have been actively carried out, taking advantage of these benefits.
Materials that have widely been used in dental prostheses have often failed to function properly due to their low mutual bonding capacity. Various methods of treating the surface of ceramic, a material known to have a low bonding capacity, have been reported [6], and among them, approaches that modify the surface of dental materials using low-pressure plasma have been introduced as an effective way to increase their bonding capacity. Low-pressure plasma secures super hydrophilicity and increases wettability by treating the surface for a short period of time, and it also increases the bonding capacity of the surface of the ceramic, improving its bond strength [7]. In addition, argon plasma is also found to increase the shear bond strength of ceramic.
Low-pressure plasma generators are mostly used for industrial purposes. Compared to the size of dental prostheses, their capacity and scale are too huge to be used. Since the methods of generating plasma, the range of power supply, variables and the size of generators are fixed, it is very difficult to control and apply them to the size of dental prostheses. In addition, the application range of industrial plasma surface treatment is generally very broad, but the process conditions of dental prostheses are very limited compared to those for industrial purposes, requiring the design of processes optimized for these conditions.
Therefore, this study aimed to produce small chamber-type low-pressure plasma equipment for surface treatment in order to

evenly treat dental prostheses with plasma and improve their shear bond strength. Plasma was designed to be generated under the following conditions: 8~50W power supply; 48kHz frequency; and 130mTorr minimum vacuum degree. In addition, the performance of the plasma generated in this study was verified by measuring the shear bond strength of dental prostheses on which the surface was treated with low-pressure plasma.

2. Materials and Methods

2.1. Development of Small Plasma Surface Treatment Equipment for Dental Purposes

Dental prostheses are generally smaller than materials used for industrial purposes, and thus it is necessary to reduce the size of dental equipment for surface treatment. In addition, industrial plasma surface treatment can be applied to broad areas in general, but the process conditions of dental prostheses are limited compared to those for industrial purposes. As such, it is important to design small equipment for low-pressure plasma surface treatment that is optimized for these conditions.

2.1.1. Designing of Low-Pressure Plasma Surface Treatment Equipment

Small low-pressure plasma equipment is largely composed of chamber, power supply, controller, vacuum, etc. The chamber used in this study was designed to be small in order to easily treat the surface of dental prostheses and to minimize any unnecessary waste of gases and power in the process of surface treatment. In addition, a power supply must not only steadily supply a certain level of voltage and current in the process of plasma treatment, but also must be designed to reduce the size of equipment. The controller used in this study was designed to manage voltage, current and vacuum degree in the process.

Finally, vacuum is essential to maintaining an atmosphere within the chamber that is suitable to generate plasma in the process of the plasma surface treatment. Figure 1 shows a simple diagram of a small plasma surface treatment device.

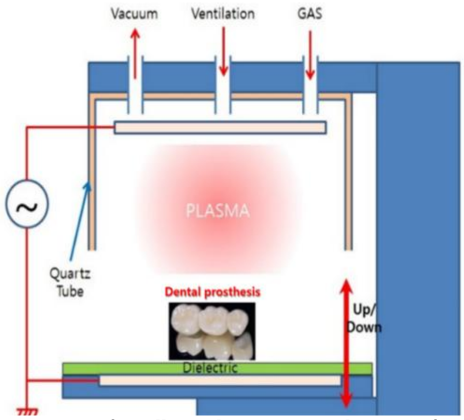

Figure 1: Diagrams of small size low-pressure plasma surface treatment equipment

2.1.2. Development of Power Supply For Low-Pressure Plasma Surface Treatment Equipment

The power supply was optimized and developed by focusing on production and output properties from the stage of designing its circuit, rather than using standard power supplies, due to differences in process conditions and size.

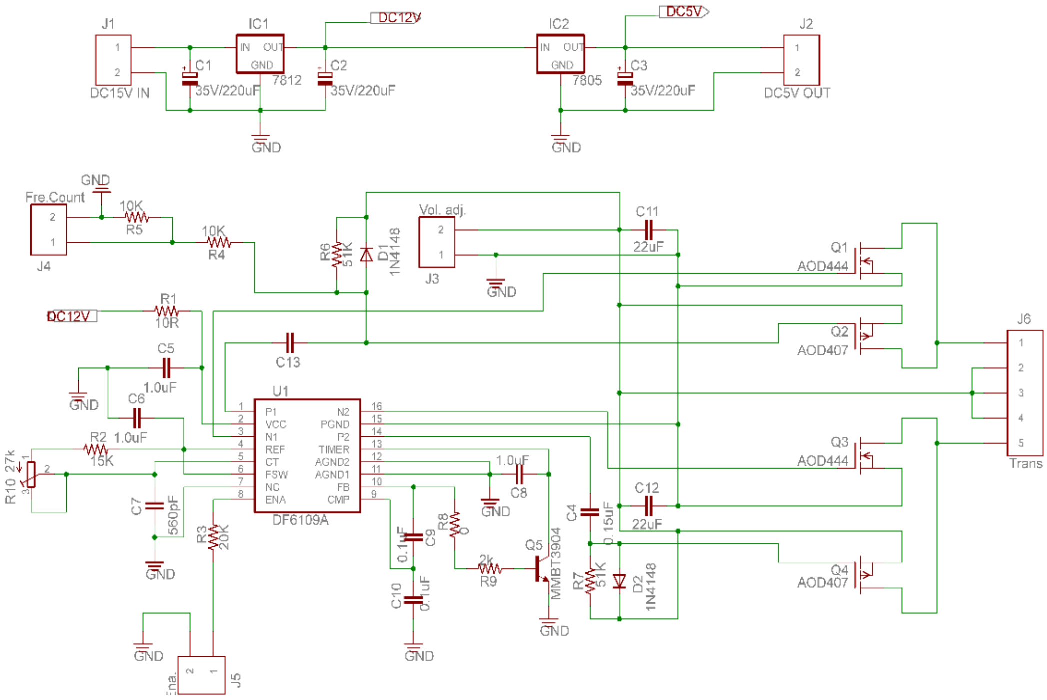

Figure 2: Circuit design of Power supply for small size low-pressure plasma surface treatment equipment

In order to steadily supply a certain level of voltage and current to the developed small low-pressure plasma device, a power supply circuit was designed as shown in Figure 2, and based on the circuit, a PCB circuit was produced for the power supply optimized for the device (Figure 3).

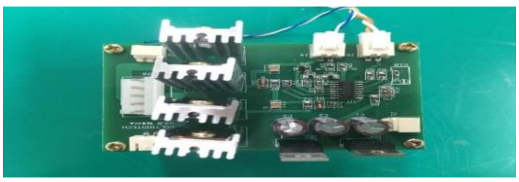

Figure 3: Power supply for small size low-pressure plasma surface treatment equipment

2.2. Analysis of the Properties of Small Low-Pressure Plasma Surface Treatment Equipment

Low-pressure plasma surface treatment was performed on zirconia samples using the small low-pressure plasma surface treatment equipment developed for dental purposes, and after that, their shear bond strength was measured to analyze the properties of surface treatment.

2.2.1. Low-Pressure Plasma Surface Treatment

Since the equipment was developed not for general low-pressure plasma surface treatment for industrial uses, but for plasma surface treatment for dental prostheses, process conditions slightly differ. The differences between the existing methods and the process were listed in Table 1.

Table 1: Surface treatment condition of existing products and dental prostheses

Index	**Atmospheric Plasma Jet (POLYBIOTECH. Co., Ltd)**	**Low-Pressure Plasma surface treatment equipment**
Condition	**2kV / 5mA / 10W**	**625V / 13.7mA / 8.6W**

As the table above shows, one of the differences between the atmospheric plasma jet process and the low-pressure plasma surface treatment process was allowable current, which can differ slightly depending on the size of target products. Since the size of dental prostheses is very small and has complicated shape, every single part needs to be controlled in detail for plasma surface treatment. To accomplish this, 13.7mA of current was applied, and a zirconia disk (diameter: 15mm, thickness: 2.4mm) was used, as shown in Figure 4.

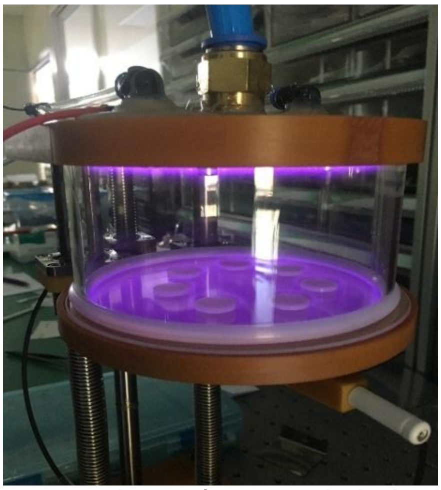

Figure 4: Low-pressure plasma surface treatment by developed equipment

2.1.2. Development of Power Supply for Low-Pressure Plasma Surface Treatment Equipment

Zirconia disks were treated with low-pressure plasma. The resin blocks (diameter: 6mm, thickness: 3mm) were attached on the surface of the zirconia disks. The shear bond strengths were evaluated using crosshead speed of 0.5mm/min.
The control group was not treated. The zirconia samples were treated with two types of equipment, the atmospheric plasma jet (POLYBIOTECH Co., Ltd, Korea) and the low-pressure plasma surface treatment equipment developed in this study. The conditions of plasma treatment were as shown in Table 2.

Table 2: Experimental conditions depending on plasma equipment

Index	Plasma equipment	Type and flow of gas	Treatment time	Others
Control group	-	-	-	-
AP group	Atmospheric plasma jet (10W)	Ar (99.999%) 5L/min	10 min	Distance between the jet and the sample: 8mm
LP group	Low-pressure plasma surface treatment equipment (8.6W)	Ar (99.999%) 500cc/min	10 min	Chamber

3. Results and Discussion

Before measuring the shear bond strength of the treated surface using the small low-pressure plasma surface treatment equipment, the output of the power supply developed in this study was analyzed using an oscilloscope, and the results are as shown in Figure 5. The waveform of the output of the power supply was found to be regular, which indicates that the output of the power supply was steady, and that it has a frequency of 48kHz.

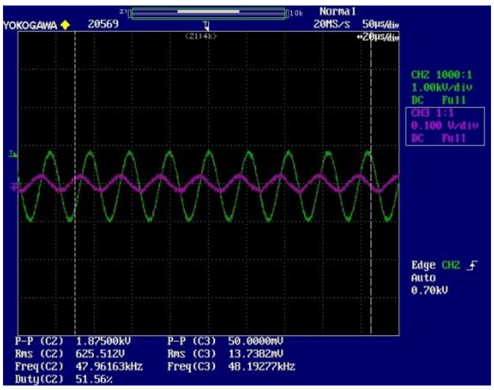

Figure 5: Result of power supply's output properties analysis by oscilloscope

The shear bond strengths were as shown in the following graph and table (Figure 6 and Table 3). Compared to the shear bond strength of the control group, all the experimental groups treated with plasma showed an increase in their shear bond strength, and the LP group showed a statistically significant increase ($p<0.05$).

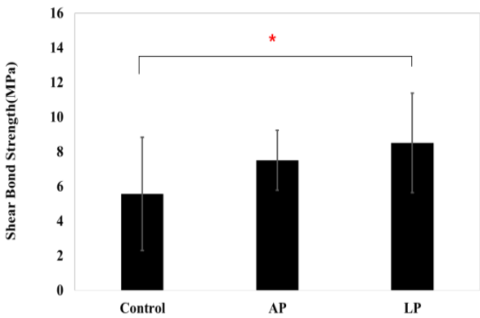

Figure 6: Results of Shear bond Strength on the group *Significant at $P<0.05$.

Table3: Shear bond strength according to surface treatment conditions

Group	**Control Group**	**AP Group**	**LP Group**
Shear bond trength (MPa)	**5.57±3.28**	**7.51±1.73**	**8.50±2.87**

The control group, for which the surface was not treated with low-pressure plasma, showed a shear bond strength of 5.57±3.28 MPa, while shear bond strength of the groups treated with the atmospheric plasma jet and low-pressure plasma surface treatment equipment was 7.51±1.73 MPa and 8.50±2.87 MPa respectively, an increase of 34% and 52.0% compared to the control group.
The atmospheric plasma jet is a plasma surface treatment device used for industrial purposes, but according to an earlier study on the shear bond strength of dental prostheses treated with plasma, its surface treatment properties are suitable for dental treatment. Therefore, the low-pressure plasma surface treatment equipment shows similar shear bond strength properties and was developed for dental prostheses.

4. Conclusion

The analysis using an oscilloscope found that the power supply optimized for the low-pressure plasma surface treatment equipment showed an output of 48kHz in the form of sine waves, and a steady allowable current output of 13.7mA was also observed in the process of plasma surface treatment. In addition, the results also indicated that low-pressure plasma surface treatment did not cause any damage to the surface of the materials of dental prostheses.
This study identified the effect of the low-pressure plasma surface treatment equipment with the power supply on improving the shear bond strength between materials that are widely used in dental prostheses such as zirconia and resin. In particular, compared to the group for which the surface was not treated, the group treated with low-pressure plasma showed an approximately 52% increase, which is also a big difference (34%) from the shear bond strength of the group treated using an atmospheric plasma jet that is partially utilized in dental prostheses.
Therefore, the low-pressure plasma surface treatment equipment developed in this study by focusing on dental prostheses was found to function better than other types of surface treatment equipment (atmospheric plasma jet, etc.) and to be highly cost-effective and convenient thanks to its reduced size, and it is expected to be utilized in treating the surface of dental prostheses with plasma.

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