



Development of Wear Test Machine for Dental Crown

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Abstract

Dental crown is a replacement materials used to repair the damage on human teeth which has been developed continuously. The wear resistance of the surface is one of the most important features. The resistance depends on the type of materials, the usage, and the environment which change constantly.

This research was aimed to study and develop wear testing machine of dental crown by simulating the oral motion, the load in the process of chewing, and the oral environment. By applying the method of pin on flat test with AC Servo Motor and microcontroller, the load control system was stable and responsive to where it can adjust the load accurately during the test. The machine was designed to test the surface that resembles the curve of the crown. The two axes were moved, mimicking the movement of the teeth in the oral cavity, which was moving one way and reciprocating by controlling oscillator movement of cyclic loading between 16 to 36 N, characterizing a sine curve with a load cell measured force and friction at 37° C, pH = 7 and frequency of 0.5 and 1 Hz.

Wear testing machine for dental crown can be used to test the synthetic materials in dentistry for the suitable use at present and in the future.

Keywords: Dental crown, Wear test machine, Pin on flat.

1. Introduction

Human teeth could be worn out from many determinants such as the way people use their teeth, accidents, and aging. Therefore, teeth have to be taken proper care. When teeth are worn out, one of the methods to solve the problem is Dental Crown. The restorative material should have the same or better quality compared to real human teeth material. The friction caused by chewing and biting corrodes

only 10-40 μm thick layers per year while the average wear rate on restorative dental materials on contact-free surfaces in clinic conditions are 8.5-9.2 μm per month under microscopic and laser scanner measurement [1,2]. The normal restorative dental materials are much weaker than the natural human teeth.

Many studies and developments were performed to create a material-testing machine in order to improve the dental crown material.



The material-testing machine was to be created on the three basic areas: force, movement, and oral condition simulation, including saliva or artificial saliva [3].

The various testing methods have been developed to simulate human oral. The previously-used methods are, for instance, the servo hydraulic system; The University of Alabama at Birmingham system (UAB); The ACTA system; The OSHU system. Regarding the servo hydraulic system, both attrition and abrasion are stimulated one at a time with diverse forces [4], while the University of Alabama at Birmingham system (UAB) consists of stylus, round or cone shapes that oppose a flat specimen [5]. The ACTA system is composed of two wheels rotating against each other with artificial [6], while the OSHU system can excellently perform both attrition and abrasion at the same time [7].

This study was aimed to build a dual-axis wear test machine to test the wear resistance of dental materials in terms of force, movement, and oral environment.

2. Materials and methods

2.1 The device of machine

This machine simulated the movement during chewing process in human oral for the purpose of studying the wear resistance of dental crown (Fig. 1). The machine could test on both cycling loading (the forces are varied) and constant loading of a testing sample. The loading was controlled by Panasonic AC Servo Motor Driver (model MSDA203A1A). During the test, the AC motor worked interchangeably

between position control mode and torque control mode. The position mode worked on the vertical movement of the ball screw to make the stylus – a part made from stainless steel with a rounded-shape end with diameter of 2 mm - that contacted the sampling material in the container box. Then the machine switched into torque mode. It depended on the user to adjust the constant force for standard testing or cycling mode. The process was to simulate chewing by controlling the loading on the stylus, which a half sine curve character. In this process, the flat plate and the force control on Y-axis were moving horizontally at the same time. The plate was placed on the Linear Guide Way which moved together in one direction as a cycle. The testing material was held in the flat plate which was exchangeable for different test samples. The movement on X-axis was driven through cam motion mechanism by direct current (DC) gear motor and its velocity control was used to adjust the frequency of the oscillation by DC motor driver. The last position before the machine switched back to position mode moving the ball screw, lifting the stylus from the material was where the motor moved in half circular. Then, the motor would move another half a circle and take the plate back to the original position. The testing can be continued as required. The range of the plate movement can be adjusted by choosing different radius of a circle shape cam.

A thermal unit and water were also applied to the wear testing. The pump was equipped to circulate water at a constant temperature with a heater controlled by a



temperature control, connected to the container. The pump would inject water onto the crown surface to control the testing material's temperature and act as artificial human saliva. The waste water would be drained out as un-reusable water to prevent the effect from floating fractures of the testing material.

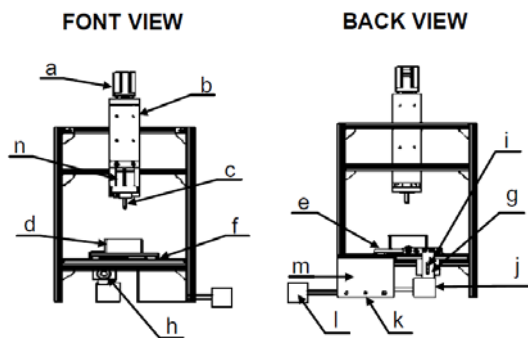


Fig. 1 Schematic drawing of the machine: (a) AC motor, (b) ball screw, (c) stylus, (d) container box, (e) flat plate, (f) Linear Guide Way, (g) cam motion mechanism, (h) direct current (DC) gear motor, (i) adjusted range of the plate, (j) pump, (k) heater, (l) temperature control, (m) water container and (n) load cell

The load system can be calibrated from load cell, together with data locker. In torque mode control, the analog signal followed a desired loading pattern which was generated and sent to the driver. Then, the signal from the driver would be sent to the AC motor to control the load. For position control, the position of the stylus could be managed by pulse signal. Both analog signal and pulse signal were controlled by microcontroller which was controlled and displayed by computer. The performance of the testing machine feature is shown in Table 1

Table. 1 Properties of the testing machine

Motion	Two axis
Type to test	Ball on flat, Pin on flat, Flat on flat
Frequency (Hz)	0.25 to 1
Loading (N)	0 to 200
Load pattern	Constant loading and Half sine loading
Sliding	One way and reciprocating
Range of motion (mm) (specimen size)	5 to 25
Temperature ($^{\circ}$ C)	30 to 80

2.2 The machine control system

This control system required the microcontroller (model 16F877A) to generate signal to control board drive which included both AC motor and DC motor. It would receive input value for the testing and display via computer. The HyperTerminal program was used to communicate between the computer and the controller through RS232.

2.2.1 AC servo motor

The torque control mode would receive an analog signal into the board drive, controlling an AC motor to generate the required load. This board drive controlled the motor as shown in Fig. 2.

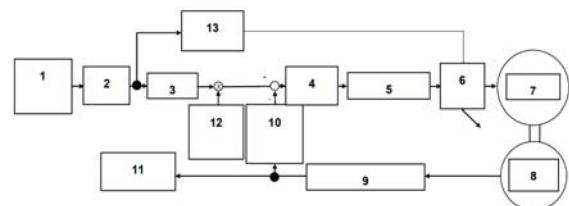


Fig. 2 Block diagram of AC servo drive in torque control mode: (1) Analog torque command, (2) Input setting, (3) Sign (+-), (4) Speed Control,



(5) Torque filter, (6) Torque limit, (7) Motor, (8) Encoder, (9) Encoder receive processing, (10) Speed detection and filter, (11) Feedback pulse, (12) Internal speed limit and (13) Absolute (Magnitude)

The position control mode would receive pulse signal into the board drive controlling the position with a feedback from encoder as shown in Fig. 3.

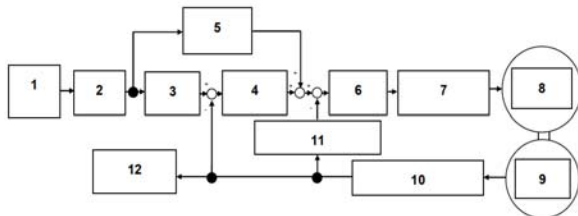


Fig. 3 Block diagram of AC servo drive in position control mode: (1) Input PULS and SIGN, (2) Input setting, (3) Filter function, (4) Position control (PI control), (5) Speed feed foreword, (6) Speed Control, (7) Torque filter (Limit Torque), (8) Motor, (9) Encoder, (10) Encoder receive processing, (11) Speed detection and filter and (12) Feedback pulse

2.2.2 DC Gear Motor

There was a drive board which had an h-bridge structure to control the motor. It could temporarily get the maximum current of 30 A and the continuous drive current of 9 A with voltage at 24 VDC, receiving logic signal from controller with voltage 3-5.5 VDC. The frequency that was used to control the PWM was up to 1 kHz and separated the power signals from the control signal from the drive motor with OPTO-Isolator to prevent interference from the motor. As shown in Fig. 4.

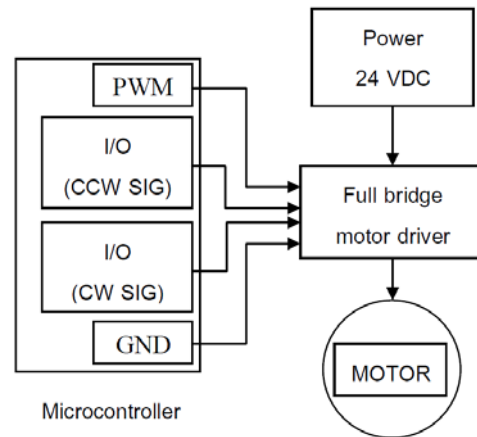


Fig. 4 Drive board with an h-bridge structure to control the motor.

2.3 wear test procedure

2.3.1 Test Machine and Material

The dental material was mounted to the plate with screw for testing by casting the material with epoxy resin (mixing ratio by weight with resin 100: hardener 15). It had a cylindrical shape with diameter 25 mm and 15 mm high.

The testing was simulating human oral with one way and reciprocating movement, cycle loading and temperature to study about the wear rate of material.

Wear material analysis was performed in two different ways (one way and reciprocating) at a none-constant load (cycling load) condition with two different frequencies (0.50 Hz and 1 Hz), the parameters were chosen on the normal conditions of human oral. The load has a maximum of 36 N, frequency 1 Hz, stroke length of 1.5 mm, temperature 37°C, pH 7, and number of cycles 5,000 for testing.

All of these experimental results are shown in table 2

Table. 2 Condition for tested dental materials.

Condition	One way		Reciprocating	
	1	0.5	1	0.5
Frequency (Hz)	1	0.5	1	0.5
Loading maximum (N)	36	36	36	36
Temperature (°C)	37	37	37	37
pH	7	7	7	7
number of cycles	5,000	5,000	5,000	5,000

2.3.2 Data Measurements

The data locker (Vishay Strain Smart Data Acquisition System 5000) was used to measure loading during the wear and simulator test.

The data locker received analog signals form load cell (1,000 N) then, converted them to digital signals on the A/D converter 16-bit gain accuracy, sampling rate 1 ms per scan and stability $\pm 0.1\%$ at 23°C ; ± 100 ppm/ $^{\circ}\text{C}$ by Signal Convertor, then the data processing would display the value of loading on the screen.

3. Result

This machine controlled loading and movement with two different methods. First, to produce a one-way movement which was similar to human mouth movement and the other was a reciprocating movement. These two movements are shown on Fig. 5.

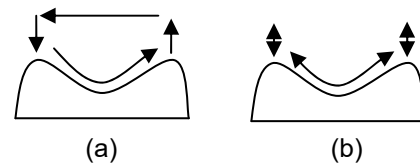


Fig. 5 the movement of the machine: (a) one way movement and (b) reciprocal movement

Loads were measured by load cell with data locker. During the test, the load (cycling load) was controlled within 0–1 second per cycle at the frequency of 0.5 Hz on dental crown and flat plate in both one way and reciprocal as shown in Fig. 6. They were also tested on 0-0.5 second per cycle at the frequency of 1 Hz on dental crown and flat page, both in one way and reciprocal as shown in Fig. 7.

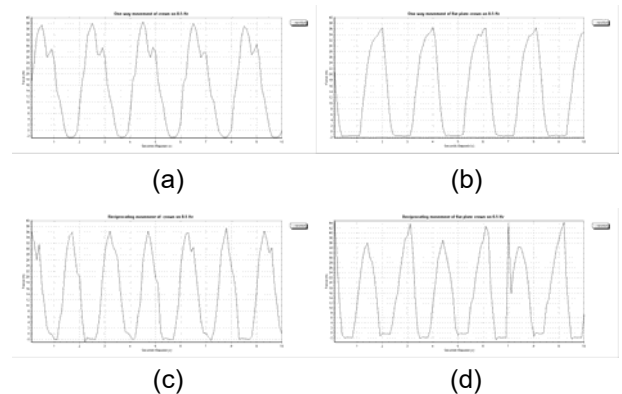


Fig. 6 Loads were measured by load cell at 0.5 Hz: (a) one way movement of crown, (b) one way movement of flat plate crown, (c) reciprocating movement of crown and (d) reciprocating movement of flat plate crown

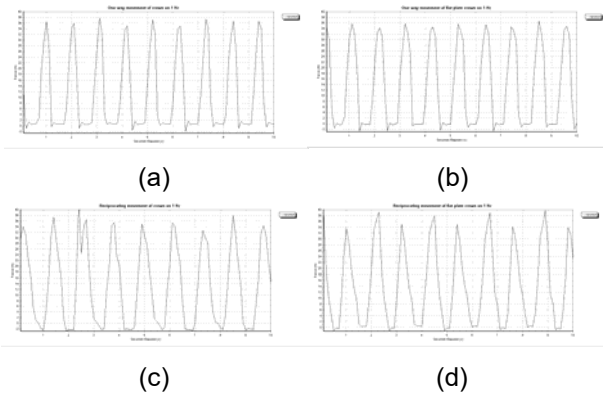
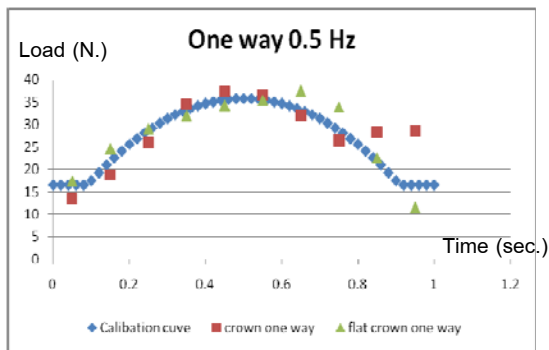
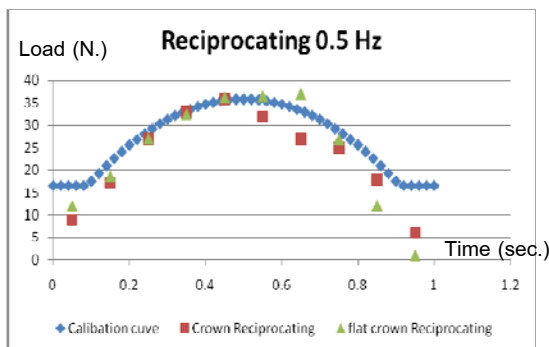


Fig. 7 Loads were measured by load cell at 1 Hz: (a) one way movement of crown, (b) one way movement of flat plate crown, (c) Reciprocating movement of crown and (d) reciprocating movement of flat plate crown

Fig. 8 displays the comparison of graphs between one way and reciprocating at the frequency of 0.5 Hz of flat plate and dental crown. Fig. 9 is also a comparison of the two at the frequency of 1 Hz. In comparison, calibration curve was used as a medium.

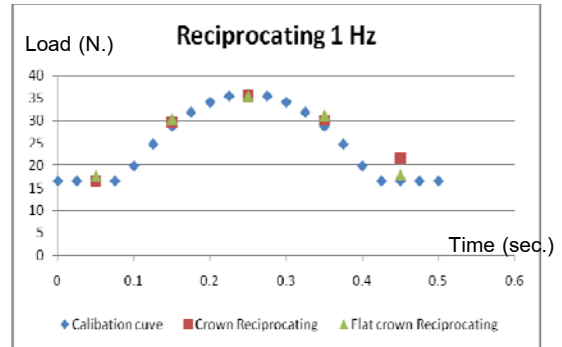


(a)

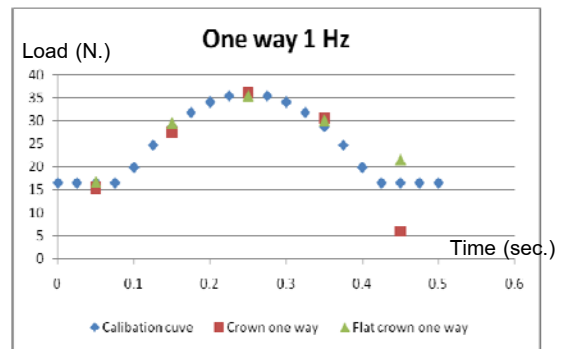


(b)

Fig. 8 comparison of graphs between crown and flat plate at 0.5 Hz: (a) one way movement and (b) reciprocating movement



(a)



(b)

Fig. 9 comparison of graphs between crown and flat plate at 1 Hz: (a) one way movement and (b) reciprocating movement

In comparing the input value with load experimental results for every movement and frequency at various times, the average error rate are 13.83% at 0.5 Hz and 8.89% at 1 Hz in one way movement of flat plate crown, 22.69% at 0.5 Hz and 6.09% at 1 Hz in reciprocating movement of flat plate crown, 14.26% at 0.5 Hz and 16.37% at 1 Hz in one way movement of crown and 21.95% at 0.5 Hz and 7.76% at 1 Hz in reciprocating movement of flat plate crown

After the test on dental crown and flat plate the result is shown in Fig. 10.

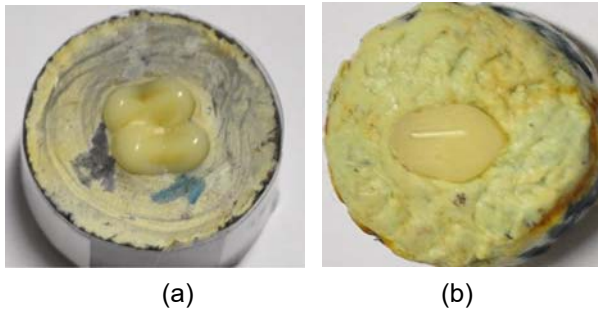


Fig. 10 (a) the test on dental crown: (b) the test on flat plate

4. Discussion

There were many attempts to generate the load and movement of the mastication system. However, it is difficult to do so as there are many parameters needed to be controlled. As the movement of human teeth is not as stable as the machines and the condition of the mouth is very complicated, the best a machine can do now is to approximate how human mouth function. Therefore, there are many methods are used to implicate the oral system. This machine had applied AC servo-motor control to control the loading to be as close as the human chewing method as possible. Shape of the load curve is similar to the positive half of sine curve wave [8]. AC servo-motor was chosen as it is very stable, responsive and easily controlled. This results in the accuracy of the test in controlling of loading. Moreover, AC servo-motor has torque control for controlling the load vertically which makes it simple to use. In this experiment, the load was chosen from the range of 16 to 36 N, which was similar to the magnitude of masticatory load of human process of chewing [9]. Unfortunately, the machine was still not able to copy the human chewing system exactly due to the fact that the motor is not able

to make a sudden movement shift. On the brighter side, this machine is considered a good wear test material. The accuracy of the system is shown in Figs.8-9. The graphs show that the control of loading is close to the calibration curve at the 1Hz-frequency test. It seems that the value of the 1Hz-frequency test is closer to the calibration curve than the 0.5Hz-frequency test. By using data locker, the sampling rate is limited. The data logger used in the test can accumulate up to 10 times per second. The frequency at 1 Hz does not give the best accuracy due to the difference of speed (1 Hz and 0.5 Hz) which affects the time spent on each cycle (1 Hz gets 5 samplings and 0.5 gets 10 samplings). The 0.5 Hz test gives a more realistic result since it does not leave out the errors. Also, these errors are in the acceptable rate.

This experiment had controlled pH and the temperature. With tap water, pH is equal to 7, which is equivalent to human saliva [10]. The temperature was also constantly controlled by the temperature control (PI control) similarly to the normal oral temperature, 37°C [3].

5. Conclusions

The machine is able to simulate various conditions of human oral. AC motor with servo drive is able to simulate load and movement of human chewing. Regarding the various conditions of the mouth, this machine can control various conditions, with the range of frequency between 0.25 Hz and 1 Hz and the temperature ranges from 30 to 80°C. Thus, this wear machine for dental crown can be use in



the future to test other synthetic materials of dental crown.

6. Acknowledgement

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7. References

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