A SURFACE TOPOGRAPHY STUDY OF THE UNTREATED AND HEAT-TREATED ZIRCONIA DENTAL CROWNS MANUFACTURED THROUGH CNC DENTAL MILLING MACHINE

This report is submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)

by

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FACULTY OF MANUFACTURING ENGINEERING

2021

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

Tajuk: **A SURFACE TOPOGRAPHY STUDY OF THE UNTREATED AND HEAT-TREATED ZIRCONIA DENTAL CROWNS MANUFACTURED THROUGH CNC DENTAL MILLING MACHINE**

Sesi Pengajian: **2020/2021 Semester 1**

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APPROVAL

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ABSTRAK

Zirconia adalah salah satu seramik pergigian yang paling banyak digunakan, dan menjadi popular sejak beberapa tahun kebelakangan ini kerana sifat mekaniknya yang sangat baik, yang membolehkannya digunakan sebagai bahan rangka untuk pembuatan mahkota gigi, jambatan atau penggabungan gigi dan implan gigi. Selain itu, penemuan sistem pengilangan medan gigi CAD/CAM telah menjadikan seramik zirkonia sebagai bahan asas untuk pemulihan gigi. Walau bagaimanapun, pemulihan mahkota gigi semasa penggilingan CNC yang tidak dirawat menunjukkan sifat mekanik permukaan yang sederhana kerana pesongan reflektif antara bahan kerja dan alat pemotong semasa proses penggilingan. Tujuan kajian ini adalah untuk membandingkan topologi permukaan pemulihan mahkota gigi yang dirawat haba dan tidak dirawat yang dihasilkan melalui mesin penggilingan gigi CNC. Blok Y-TZP Zirkonia telah digunakan untuk membuat 12 sampel mahkota gigi. Sampel mahkota gigi telah dibahagikan kepada dua kumpulan iaitu 3 sampel untuk mahkota gigi yang tidak dirawat dan 9 sampel untuk mahkota gigi dengan rawatan haba. 9 sampel mahkota gigi telah menjalani rawatan haba pada tiga suhu yang berbeza iaitu 850°C, 950°C, and 1050°C. Pada setiap tetapan suhu, 3 replikasi sampel telah digunakan. Selepas itu, sampel yang dipilih telah diperiksa dengan menggunakan alat ujian kekasaran permukaan. Pengukuran kekasaran permukaan telah dijalankan dengan menggunakan 2 sampel dari setiap kondisi mahkota gigi.Selepas itu, mahkota gigi yang dipilih telah disaluti dengan lapisan emas. Perbandingan permukaan topografi mahkota gigi yang tidak dirawat dan dirawat haba telah dilaksanakan menggunakan mesin pengimbas mikroskop elektron dengan kuasa pembesaran 50x. Keputusan dari pembelajaran ini telah membuktikan bahawa rawatan haba menggunakan suhu 850°C, 950°C, and 1050°C tidak dapat memperbaiki permukaan gigi. Mikrostruktur analisis telah menunjukkan kesan permukaan tidak rata masih lagi kelihatan selepas rawatan haba. Daripada keseluruhan keputusan, suhu yang digunakan adalah tidak mencukupi untuk mengurangkan kekasaran permukaan pada mahkota gigi Zirkonia.

ABSTRACT

Zirconia is one of the dental ceramics most widely used, which has become popular over recent years due to its excellent mechanical properties, which allow it to be used as a frame material to manufacture crowns, bridges or dental abutments and dental implant. On the other hand, the invention of CAD/CAM dental-field milling systems has made zirconia ceramics a standard material for dental restoration. However, the untreated CNC milled restoration shows moderate surface quality because of the reflective deflection between the workpiece and the tool cutter during milling operation. The aim of this study is to compare the surface topology of the untreated and heat-treated dental crown restoration manufactured through CNC dental milling machine. Y-TZP Zirconia block was used to manufacture 12 crown samples. The crown samples were divided into two groups, which 3 samples are for the untreated and 9 samples are for the heat-treated condition. 9 crowns samples were conducted for a heat treatment at three different temperature setting which is 850°C, 950°C, and 1050°C. At each temperature setting, three replication of the sample were adopted. After that, the selected samples were examined using a surface roughness tester. The measurement was carried out using two samples from each condition. After that, the selected crowns were sputter-coated. The surface topography comparison of the untreated and heat-treated crown restoration was executed using the Scanning Electron Microscope (SEM) machine with 50x power magnification. The result from this study showed the heat treatment of 850°C, 950°C, and 1050°C does not improve the surface quality of the crowns. The microstructure analysis shows the scallop-height effects still exist after the heat treatment. In conclusion, the temperature used in this study is not sufficient to improve the surface quality of the Zirconia dental crown. Also, the surface roughness tester plays a significant role in measuring the crown's surface. As a recommendation, a higher temperature in between 1300°C-1500°C shall be used for heat treatment.

DEDICATION

To

My late father, Che Wan Jaafar bin Che Wan Endut

My beloved mother, Nor Isah binti Abdullah

My brothers and sisters, Che Wan Nor Azlina

Che Wan Jasni

Che Wan Junaidi

Che Wan Juliana

Che Wan Nor Aida

for giving me moral support, money, cooperation, encouragement and also understandings

Thank You

ACKNOWLEDGEMENT

In the name of ALLAH, the most gracious, the most merciful, with the highest praise to Allah that I manage to complete this final year project successfully without difficulty.

I would like to express my deep and sincere gratitude to my respected supervisor, Dr. Rahimah binti Abdul Hamid, for giving me the opportunity to do this study and providing invaluable guidance throughout this study. Her kind supervision, sincerity, and motivation have deeply inspired me. She has taught me many kinds of things and exposed me to meaningful experiences during my final year project. It was a great privilege and honor to work and study under her guidance.

Next, a special thanks of gratitude to En Mohd Hanafiah bin Mohd Isa, Pn Siti Aisah binti Khadisah, and En Bahatiar bin Zaid, who have been so warm and kind to provide sincere assistance and good cooperation during the final year project period.

Last but not least, my deepest gratitude and thankfulness are dedicated to my beloved mother for her prayers, support, and sacrifices for educating and preparing me for my future. Also, I express my thanks to my brothers and my sisters for their support and valuable motivation. Not forgetting to all of my friends and all of the people who have helped, support, and contributed to complete my final year project. I have no valuable words to express my thanks, but my heart is still full of favors received from every person. Thank you very much.

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LIST OF ABBREVIATIONS

CAD/CAM	-	Computer-Aided Design & Computer-Aided Manufacturing
CNC	-	Computer Numerical Control
SEM	-	Scanning Electron Microscope
FPM	-	Porcelain fused to metal
Au	-	Gold
3D	-	Three-dimensional
FPD	-	Fixed Partial Dentures
Y-TZP	-	Yttria-Stabilized Zirconia
PMMA	-	Poly (methyl methacrylate)
ZrO2	-	Zirconium Dioxide
LMGC	-	Lithium Metasilicate Glass
CIP	-	Cold Isostatic Pressing
LM	-	Light Stereomicroscopy
DCP	-	Direction of Crack Propagation
EDS	-	Energy Dispersive X-Ray Spectroscopy
EBSD	-	Electron Backscatter Diffraction
FEG-SEM	-	Field Emission Gun Scanning Electron Microscopy
PSM	-	Projek Sarjana Muda
STL	-	Stereolithography
AC	-	Alternating Current
FKP	-	Fakulti Kejuruteraan Pembuatan
LCD	-	Liquid Crystal Display
WD	-	Work Distance

LIST OF SYMBOLS

μm	-	Micrometre
m	-	Metre
%	-	Percent
mm	-	Millimetre
MPa	-	Mega Pascal
°C	-	Degree Celsius
nm	-	Nanometre
kg	-	Kilograms
mm/min.	-	Millimetre per Minute
kN	-	Kilo Newton
m	-	Metre
°C/min	-	Degree Celsius per Minute
mm	-	Milimetre
rpm	-	Revolution per Minute
v_c	-	Cutting Speed
a_p	-	Depth of Cut
V_f	-	Feed Rate
Q′	-	Specific Material Removal Rate
Ra	-	Average Roughness, Arichmetic Mean
σ	-	Standard Deviation
Sa	-	Mean Arithmetic Deviation
Rz	-	Average Maximum Peak to Valley
m/s	-	Metre per Second
mm/min	-	Millimeter per Minute
P	-	Dynamic Viscosity
kV	-	Kilovolt
N	-	Newton
HV	-	High Voltage

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Dental crown restorations are made to cover a damaged or cracked tooth. Dental crowns can even be used to dress up a tooth that is very worn or discolored. Basically, a dental crown restoration is defined as a tooth-shaped "cap" that is placed over a damaged or cracked tooth. The purpose of the crowns is to cover the damaged tooth to restore its size and shape, strength, and get better appearances. Other than that, the crowns are made to protect a weak tooth from fracturing or to maintain together parts of a cracked tooth. For children, a crown restoration is usually used on primary teeth to guard a child's teeth at a high risk of tooth decay, especially when a child has trouble keeping up with regular oral hygiene.

In the dentistry sector, many types of material are used for manufacturing of crown restoration. For example, stainless steel crowns are prefabricated crowns primarily used as temporary measures on permanent teeth. The crown covers the tooth or the filling, while the permanent crown is made of a different material. For kids, the stainless steel crown is typically used to fit over the primary tooth that has been ready to fit it. The crown protects the whole tooth and prevents it from further decay. Other than that, there is much other material that is used for a crown restoration, such as metal alloys, porcelain-fused-to-metal, gold, porcelain, lithium disilicate, and Zirconium. Zirconium has become a relatively new material that combines metal strength with porcelain crown aesthetics. High translucent Zirconia and layered Zirconia crowns have recently become a more popular choice.

The Zirconia crowns are made from Zirconia blocks, a type of metal that is incredibly tough, and that is related to titanium, but it is categorized as a ceramic crown.

Crown restoration manufactured from Zirconia has a high demand among people because they provide many advantages compared to other materials. One of the main challenges in the dental field is ensuring the use of biocompatible materials for restoration methods that can stand up with the pressure executed by force during chewing. Zirconia is much stronger than porcelain, which has five times the strength compared to porcelain and other types of crowns. For patients that have fractures, cracks, or other broken crown problems, Zirconia is an excellent choice. Zirconia is much more resistant to stain than ceramic composites or acrylic crowns. The ability to better resist warm, hot, and cold temperatures can help protect against other crowns' often seen hyper-sensitivity. Zirconia crowns have low thermal conductivity and do not pass extreme temperature fluctuations as different crowns have.

For decades, the dental prosthesis has been a typical method of restoration, but like many other medical sectors, the strategy, material and technology that want to create these restorations have evolved. The invention of CAD/CAM dental milling systems has made Zirconia ceramics a standard material for dental restoration. A quick and individual method to manufacture Zirconia dental restorations is provided by the CAD/CAM milling systems. Smoother and hydrophilic surfaces of the CAD/CAM restoration crowns must have more advanced than traditional dentures. The drawbacks of these methods are limited accuracy and the potential of microscopic cracks.

The untreated CNC milled restoration has shown moderate surface roughness because of the reflective deflection between the workpiece and the tool's cutter during milling operation. Surface roughness is one of the critical characteristics of the microbial attraction of tooth surfaces and must be controlled in order to prevent any patient distress during use. The increasing surface roughness between 0.1 and 0.4 µm enhances the microbial adhesion. Kim *et al.* (2015) confirmed that the in-vitro study had shown the different amounts of bacterial adhesion of materials with extremely low surface roughness. Bollen *et al.* (1996) stated the surface roughness of the Ra-cut-off value of 0.2 µm is not affected by bacterial adhesion or colonization, which is less than this Ra-value. Therefore, in this study, the untreated surface roughness and the heat-treated CNC milled Zirconia restorations were examined using SEM machine in order to see the impact of heat treatment towards the surface quality of the crown.

1.2 Problem Statements

The surface roughness of the dental restorations is one of the important factors which are believed could contribute to the accumulation of microbial in the mouth during use. Therefore, it is vital to ensure the surface roughness of any restoration is within the acceptable limit. CNC milled dental crown exhibits a variation of surface roughness, which is mainly depending on the complex profile of the crown, in addition to the physical contact of the tool and the Zirconia block during the machining process. The first hypothesis of this study is there will be some scratch grooves and also a scallop height effect that could be encountered on the untreated crown as the outcome of the milling operation.

In order to overcome these milling operation drawbacks, the heat treatment of the dental crown is expected to reduce the pores and subsequently improve the surface texture. However, the appropriate temperature of the heat treatment is still unknown and could be based on the phase diagram or from the recommendation by other researchers. Therefore, the second hypothesis of this study is there will be an improvement of the surface roughness of the dental crown after the heat treatment. As a result, a study on the surface topography of the untreated and heat-treated dental crown was carried out using a Scanning Electron Microscope (SEM) machine in order to record the differences. On the other hand, a measurement of the surface roughness for both conditions was executed using a surface roughness tester. This was challenging due to the complex geometrical of the dental crown. In addition to the capability of the used surface roughness tester, a selection of where to place the measurement is also important in order to reduce any possible measurement errors.

1.3 Objectives of Study

a) To compare the surface topography of the untreated and heat-treated Zirconia dental crowns using the Scanning Electron Microscope (SEM) machine.

b) To analyze the surface roughness of the untreated and heat-treated dental crown using a surface roughness tester.

1.4 Scopes of Study

a) The Zirconia crown specimen was heated at 850-1050°C for the heat treatment.

b) The number of crown replications is three for each condition due to the expensive Zirconia blocks.

c) A CAD file of the dental crown in the machine was directly used to fabricate the specimens. The scanning of new crowns does not require due to the limitation of a capable 3D scanner.

d) The powder coat used is gold (Au) to coat 12 samples of the dental crown restorations.

e) The measurement of the surface roughness test was repeated five times at each side of the crown's sample. The occlusal surface is not examined due to the complex geometric profile.

f) Two samples were used from each condition during surface roughness measurement, and one sample was used from each condition during the surface topography analysis.

CHAPTER 2

LITERATURE REVIEW

In this chapter, recent theories of dental crown restoration and publications are reviewed. Different means to produce the dental crown have resulted in different mechanical properties in terms of microstructure and strength of the fabricated crowns. Information about these variations has been studied and summarized. In addition to that, a different manufacturing method towards dimensional accuracy, surface roughness and the heat treatment of the fabricated crowns are also reviewed.

2.1 Overview of the Dental Crown

Crown and bridge restoration has been one of the general practitioner's key methods for preserving their shape and function authentically. The recent introduction of integrated Osseo implants has expanded crown and bridge restorations for partially edentulous patients. Dental crowns act as a restoration protecting or coating teeth. This also preserves the standard size, form and color of the tooth. In the meantime, it does not only offer a good look, it also strengthens a tooth. These are two different crown types, one alternative is to cover a tooth that can boost the existing structure and the other one is placed over a damaged tooth. The other choice is the full reconstruction of a dental implant and it is enormously strong and usable with both options.

Aspros (2015) suggested that the metal filling in the teeth is expanding and contracting when people are exposed to hot and cold drinks or food. This can weaken teeth essentially and lead to cracking of the whole tooth. The inlay or onlay is a tooth repair just like a metal lining and even a crown. An inlay is a fill that is placed on the cusp of the tooth, while the onlay is used to preserve the cusp region that stretches over more of the tooth. The onlay of the dental crown is more preferred and has become the main focus in this study. Inlays and onlays are usually made of porcelain, acrylic resin and can also be made of gold. On the other hand, Bammani *et al*. (2012) has illustrated the difference between dental crown and bridges, as shown in Figure 2.1.

Figure 2.1: Diagram of dental crown and bridges (Bammani *et al*., 2012).

Bammani *et al*. 2012 highlighted that crowns could be classified into two types, which are posterior crowns and anterior crowns. Longer and thinner teeth are built at the front of the mouth, including the lower and top cuspid incisors of both primary and secondary teeth. The posterior crowns are designed for thicker teeth in the bottom of the mouth, the bottom and top molars.

2.2 Dental Crown Material

Different materials have been used for the manufacture of dental crown restorations. For example, Hian (2017) stated the progress in the last ten years in dental ceramic and processing technology is substantial and most advances have been associated with the new CAD-CAM method and new micro-structures. The intermediate properties of the composite materials between pottery and polymer make it a preferred process by means of CAD/CAM due to the simple milling and polishing of its components. Porcelain is one of the dental ceramics used in the production of dental crowns.

In relation to that, Dolidze (2016) describes the most common aesthetic restoration material used is porcelain fused to metal (FPM) in manufactured crown and bridge restoration work because of its excellent mechanical properties. Many dentists are reluctant to use a new or moderately tested form of restoration. However, FPM has already proved itself and has been used in dentistry for more than 50 years. Nonetheless, dental work has started in order to enhance the aesthetic result for the metal-free ceramic restorations. So, the introduction of Zirconia and E-max would make the development of the perfect crown easier. E-max crown is one of the kind of ceramics crown that makes it suitable for its enduring appearance, which comes in a single block of lithium disilicate ceramic and can be graded as a highly prized ceramic for its strength, durability and opaque performance.

According to Alfawaz (2016), due to the high appearance, inertness and biocompatibility, ceramics have become popular as a dental restoration. For dental ceramics, Zirconia is one of the alternatives for ceramic materials used as a dental biomaterial for contemporary restorative dentistry. Zirconia gains clinical popularity due to excellent mechanical features and the simple use of CAD/CAM technology for green manufacturing. Moreover, the previous survey suggests that Zirconia crowns have provided an excellent substitute for restorations of prosthodontics in premolar and molar regions.

2.3 Zirconia Crown Preparation

In this chapter, the preparation of the Zirconia crown is elaborated. Firstly, the scan of the tooth has to be carried out using any 3D optical scanner to acquire an automatically accurate 3D model of the tooth, as discussed by Jang *et al.* (2011). Figure 2.2 shows the resin die and crown manufactured through CNC dental milling machine.

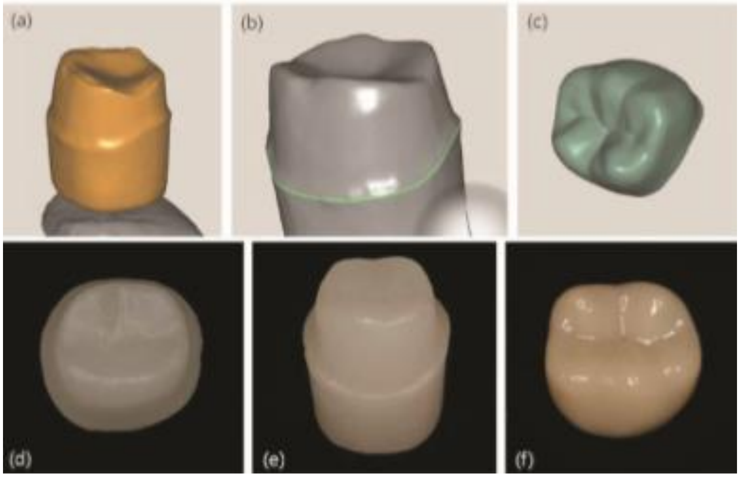

Figure 2.2: (a,b) resin die design in CAD software, (c) dental crown design in CAD software, (d, e) manufactured resin die, (f) manufactured Zirconia crown (Jang *et al.*, 2011).

A dental clinician provided a 24 h in vivo anterior fractured (canine to canine) six-unit fixed partial dentures (FPD). A dental technician in a private laboratory that trained in CAD/CAM techniques and handling Cercon System for the Zirconia framework had manufacture the Zirconia The frame of the Cercon consisted of a Y-TZP sintered with 1350°C and furnished with a porcelain feldspar. According to the dentist, the frame was manually modified by remolding the palatal surface after CAD/CAM machining (Lohbauer *et al.*, 2010). Figure 2.3 shows the anterior Zirconia bridge manufactured from Cercon System.

Figure 2.3: Cercon veneered six-unit anterior Zirconia bridge (Lohbauer *et al.*, 2010).

Cho *et al.* (2011) highlighted in the first mandibular acrylic model tooth, the 3D contour measurements were scanned using Optical Scanner (S600 Zirkonzahn) and then a typical CAD (Zirkonzahn. Modellier, Zirkonzahn, Italy) preparation for the curvature was created at a maximum 6-degree convergence angle (3 grade on each side), a deep 1.0 mm chamfer, 5 mm height preparation and 1.5-2.0 mm occlusal reduction. Occlusal reduction CAD file on the prepared tooth (CAD/CAM M5, Zirkonzahno, Italy) was inserted in a milling machine and acrylic (PMMA) dies were produced and then used as a master die in order to make all-ceramic crowns. Figure 2.4 shows the preparation dimension of the master dies, Zirconia coping design, and the fabricated Zirconia crown.

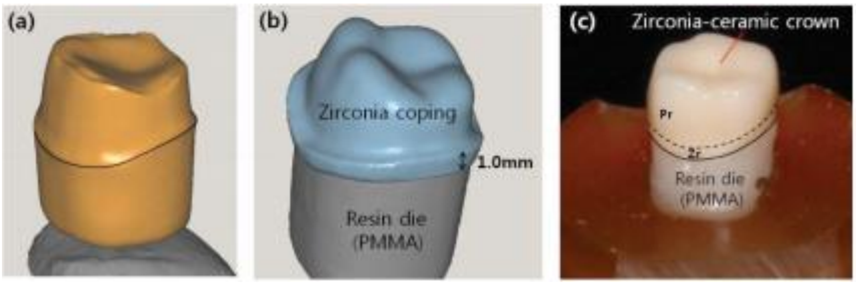

Figure 2.4: (a) Preparation dimensions of the master die, (b) Zirconia coping design with 1mm marginal collar width, (c) Fabricated Zirconia crown (Cho *et al.*, 2011).

Schmitter *et al.* (2014) have discussed the Zirconia veneer was developed with commercial dental software CAD/CAM (Dental Designer; 3Shape, Copenhagen, Denmark) and modified at the edge of the incisor. Performing two modifications, which is, the oral part of the veneer beneath the edge of the incisor was made planar and subsequently, an ellipsoidal bump (4mm× 1.5mm× 0.5mm) was placed at the location of the planned load application point (Schmitter *et al.*, 2014). The CAD-constructed maxillary incisor crown is shown in Figure 2.5.

Figure 2.5: CAD-constructed maxillary incisor crown with the modified area (raised ellipsoid) on the oral side (Schmitter *et al.*, 2014).

Anna *et al.* (2014) stated the two Zirconia blocks Ivoclar IPS e.max ZirCAD (LOT:PX0075) of three bar-shaped specimens (28 mm x 4 mm x 2 mm) and Wieland Zeno Zr were sintered to maximum density using CAD/CAM technology, polished with