EFFECT OF METHYL FORMATE-METHYL ACETATE TREATMENT ON FLEXURAL STRENGTH BETWEEN DENTURE BASE AND SELF-CURED HARD RELINE MATERIALS

Mr. Mongkol Puangpetch

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science in Prosthodontics
Department of Prosthodontics
Faculty of Dentistry
Chulalongkorn University
Academic Year 2018
Copyright of Chulalongkorn University

ผลของการปรับสภาพพื้นผิวด้วยสารละลายเมทิลฟอร์เมตและเมทิลอะซิเตตต่อความแข็งแรงดัดโค้ง
ของฐานฟันเทียมอะคริลิกและวัสดุเสริมฐานฟันเทียมบ่มด้วยตัวเองชนิดแข็ง

นายมงคล พวงเพชร

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาทันตกรรมประดิษฐ์ ภาควิชาทันตกรรมประดิษฐ์
คณะทันตแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2561
ลิขสิทธิ์ของจุฬาลงกรณ์มหาวิทยาลัย

Thesis Title	EFFECT OF METHYL FORMATE-METHYL ACETATE TREATMENT ON FLEXURAL STRENGTH BETWEEN DENTURE BASE AND SELF-CURED HARD RELINE MATERIALS
By	Mr. Mongkol Puangpetch
Field of Study	Prosthodontics
Thesis Advisor	Associate Professor Chairat Wiwatwarrapan

Accepted by the Faculty of Dentistry, Chulalongkorn University in Partial Fulfillment of the Requirement for the Master of Science

.... Dean of the Faculty of Dentistry
(Assistant Professor Suchit Poolthong, Ph.D.)

THESIS COMMITTEE

.... Chairman
(Associate Professor VIRITPON SRIMANEEPONG, Ph.D.)
.... Thesis Advisor
(Associate Professor Chairat Wiwatwarrapan)
.... Examiner
(Assistant Professor Wacharasak Tumrasvin, Ph.D.)
.... External Examiner
(Assistant Professor Vanthana Sattabanasuk, Ph.D.)

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

มงคล พวงเพชร : ผลของการปรับสภาพพื้นผิวด้วยสารละลายเมทิลฟอร์เมตและเมทิลอะซิเตตต่อความแข็งแรงดัดโค้งของฐานฟันเทียมอะคริลิกและวัสดุเสริมฐานฟันเทียมบ่มด้วยตัวเองชนิดแข็ง. (EFFECT OF METHYL FORMATE-METHYL ACETATE TREATMENT ON FLEXURAL STRENGTH BETWEEN DENTURE BASE AND SELF-CURED HARD RELINE MATERIALS) อ.ที่ปรึกษาหลัก : รศ.ชัยรัตน์ วิวัฒน์วรพันธ์

งานวิจัยนี้ มีวัตถุประสงค์เพื่อประเมินผลของการปรับสภาพพื้นผิวด้วยสารละลายเมทิลฟอร์เมต และเมทิลอะซิเตต (MF-MA) ที่มีต่อความต้านทานแรงดัดโค้งระหว่างฐานฟันเทียมอะคริลิกและวัสดุเสริมฐานฟันเทียมบ่มด้วยตัวเองชนิดแข็ง โดยเตรียมชิ้นงานอะคริลิกชนิดบ่มด้วยความร้อน (Meliodent®) จำนวน 180 ชิ้น ตามมาตรฐาน ISO 20795-1 (2013) แบ่งออกเป็น 18 กลุ่ม แต่ละกลุ่มเสริมฐานด้วยวัสดุเสริมฐานฟันเทียมบ่มด้วยตัวเองชนิดแข็ง โดยกลุ่มที่ 1-3 เสริมฐานด้วย Unifast Trad®, กลุ่มที่ 4-6 เสริมฐานด้วย Kooliner®, กลุ่มที่ 7-9 เสริมฐานด้วย Tokuyama® Rebase II Fast (ไม่ทาสารยึดติด, แช่ hardener), กลุ่มที่ 10-12 เสริมฐานด้วย Tokuyama® Rebase II Fast (ทาสารยึดติด, แช่ hardener), กลุ่มที่ 13-15 เสริมฐานด้วย Tokuyama® Rebase II Fast (ไม่ทาสารยึดติด, ไม่แช่ hardener), กลุ่มที 16-18 เสริมฐานด้วย Tokuyama® Rebase II Fast (ทาสารยึดติด, ไม่แช่ hardener) กลุ่มที่ 1, 4, 7 และ 13 ไม่ทาสาร (กลุ่มควบคุม) กลุ่มที่ 2, 5, 8 และ 14 ทาด้วยสารเมทิลเมทาคริเลต 180 วินาที กลุ่มที่ 3, 6, 9 และ 15 ทาด้วยสารละลายเมทิลฟอร์เมต และเมทิลอะซิเตต 15 วินาที กลุ่มที่ 10 และ 16 ทาด้วยสารทาสารยึดติดจากผู้ผลิต กลุ่มที่ 11 และ 17 ทาด้วยสารเมทิลเมทาคริเลต 180 วินาที และสารยึดติดจากผู้ผลิต กลุ่มที่ 12 และ 18 ทาด้วยสารละลายเมทิลฟอร์เมต และเมทิลอะซิเตต 15 วินาที และสารยึดติดจากผู้ผลิต วัดความแข็งแรงดัดโค้งด้วยเครื่องทดสอบเอนกประสงค์ วิเคราะห์ข้อมูลทางสถิติโดยใช้การวิเคราะห์ความแปรปรวนสองทาง (กลุ่มที่ 1-9) และการวิเคราะห์ความแปรปรวนทางเดียว (กลุ่มที่ 1-18) ถ้าความแตกต่างอย่างมีนัยสำคัญระหว่างกลุ่ม จึงทดสอบความแตกต่างระหว่างค่าความแข็งแรงดัดโค้งเฉลี่ยของกลุ่มต่างๆโดยใช้การทดสอบของ Tukey ที่ระดับความเชื่อมั่นร้อยละ 95 วิเคราะห์ความแปรปรวนสามทางสำหรับ Tokuyama® Rebase II Fast (การแช่ hardener, การทาสารยึดติด, การปรับสภาพพื้นผิว) ผลพบว่าชนิดของวัสดุเสริมฐาน และการปรับสภาพพื้นผิว มีผลต่อความแข็งแรงดัดโค้งอย่างมีนัยสำคัญทางสถิติ ที่ระดับความเชื่อมั่นร้อยละ 95 สำหรับวัสดุเสริมฐานแต่ละชนิด กลุ่มที่ปรับสภาพพื้นผิวด้วยเมทิลฟอร์เมต และเมทิลอะซิเตต มีค่าความแข็งแรงดัดโค้งสูงกว่ากลุ่มปรับสภาพด้วยเมทิลเมทาคริเลต และกลุ่มปรับสภาพด้วยเมทิลเมทาคริเลตมีค่าความแข็งแรงดัดโค้งสูงกว่ากลุ่มที่ไม่มีการปรับสภาพอย่างมีนัยสำคัญทางสถิติที่ระดับความเชื่อมั่นร้อยละ 95 สำหรับ Tokuyama® Rebase II Fast พบว่า การปรับสภาพพื้นผิว, การทาสารยึดติด มีผลต่อความแข็งแรงดัดโค้ง อย่างมีนัยสำคัญทางสถิติ ที่ระดับความเชื่อมั่นร้อยละ 95 ส่วนการแช่ hardener ไม่มีผลต่อความแข็งแรงดัดโค้ง นอกจากนี้ กลุ่มที่ปรับสภาพพื้นผิว (เมทิลฟอร์เมต และเมทิลอะซิเต, เมทิลเมทาคริเลต) และการทาสารยึดติด มีค่าความแข็งแรงดัดโค้งสูงกว่า กลุ่มที่ทาเฉพาะสารยึดติด อย่างมีนัยสำคัญทางสถิติ ที่ระดับความเชื่อมั่นร้อยละ 95 สำหรับการปรับสภาพพื้นผิวด้วยสารชนิดเดียวกัน ค่าความแข็งแรงดัดโค้งของ Unifast Trad® สูงกว่าของ Kooliner® และค่าความแข็งแรงดัดโค้งของ Kooliner® สูงกว่าของ Tokuyama® Rebase II Fast อย่างมีนัยสำคัญทางสถิติที่ระดับความเชื่อมั่นร้อยละ 95 การศึกษาครั้งนี้แนะนำให้ใช้สารละลายเมทิลฟอร์เมต และเมทิลอะซิเตต เป็นเวลา 15 วินาทีก่อนการ เสริมฐานฟันเทียม ซึ่งสามารถเพิ่มความแข็งแรงดัดโค้งระหว่างฐานฟันเทียมอะคริลิกและวัสดุเสริมฐานฟันเทียมบ่มด้วยตัวเองชนิดแข็ง

Chulalongkorn University

สาขาวิชา	ทันตกรรมประดิษฐ์	ลายมือชื่อนิสิต	....
ปีการศึกษา	2561	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....

5975835332 : MAJOR PROSTHODONTICS
KEYWORD: Acrylic denture base Flexural strength Hard reline materials Methyl formate-methyl acetate Methyl methacrylate

Mongkol Puangpetch : EFFECT OF METHYL FORMATE-METHYL ACETATE TREATMENT ON FLEXURAL STRENGTH BETWEEN DENTURE BASE AND SELF-CURED HARD RELINE MATERIALS. Advisor: Assoc. Prof. Chairat Wiwatwarrapan

The purpose of this study was to evaluate the effect of methyl formate-methyl acetate (MF-MA) surface treatment on the flexural strength between denture base and hard reline materials. 180 heat-cured acrylic denture base (Meliodent®) specimens were prepared according to ISO 20795-1 (2013) and divided into 18 groups with various autopolymerizing hard reline materials. Group I-III: relined with Unifast Trad®, Group IV-VI: relined with Kooliner® Group VII-IX: relined with Tokuyama® Rebase II Fast (without adhesive, with hardener), Group X-XII: relined with Tokuyama® Rebase II Fast (with adhesive and hardener), Group XIII-XV: relined with Tokuyama® Rebase II Fast (without adhesive and hardener), Group XVI-XVIII: relined with Tokuyama® Rebase II Fast (with adhesive, without hardener). Group I, IV ,VII and XIII were untreated surface (control groups), Group II, V, VIII and XIV were surface treated with methyl methacrylate (MMA) for 180 s and Group III, VI, IX and XV were surface treated with MF-MA solution for 15 s. Group X and XVI were surface treated with the manufacturer adhesive, Group XI and XVII were surface treated with MMA 180 s and the manufacturer adhesive, Group XII and XVIII were surface treated with MF-MA 15 s and the manufacturer adhesive. The flexural strength was measured using a Universal Testing Machine. The data were analyzed using two-way ANOVA (group I-IX) and one-way ANOVA (group I-XVIII). If the significant differences in the groups were found, the mean flexural strengths of the groups were compared using Tukey's test at a 95 % confidence level. For Tokuyama® Rebase II Fast, the data were analyzed using three-way ANOVA (Hardener, Manufacturing Adhesive, Surface treatment). The reline material type and surface treatments significantly affected on the flexural strength ($p<0.05$). For each reline material, the flexural strength of the MF-MA treated group was significantly higher compared with that of the MMA treated group and the MMA treated group had higher flexural strength than the untreated group ($p<0.05$). For Tokuyama® Rebase II Fast, the surface treatment and manufacturing adhesive affected on the flexural strength ($p< 0.05$), but the hardener did not affected on the flexural strength ($p> 0.05$). Groups of additional surface treatment (MMA, and MF-MA) after applied with the adhesive significantly increased the flexural strength compared with the groups with only using the manufacturing adhesive ($p<0.05$). For the same surface treatment, the flexural strength of Unifast Trad® was significantly higher compared with Kooliner® ($p<0.05$). The flexural strength of Kooliner® was higher than that of Tokuyama® Rebase II Fast ($p<0.05$). This study suggests the application of MF-MA solutions for 15 s before relining procedure can increase the flexural strength between denture base and hard reline materials.

Field of Study:	Prosthodontics	Student's Signature ....
Academic Year:	2018	Advisor's Signature ....

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

ACKNOWLEDGEMENTS

This research paper was done with the help and support from many people. I greatly appreciate all those who supported me.

First, I would like to thank my advisor, Associate Professor Chairat Wiwatwarrapan, for his supporting me in any way he could.

Second, I would like to thank the staff in the Prosthodontic laboratory and Dental material science research center for their assistance.

Third, I would like to thank the Graduate school for providing me the research funds for this study.

Mongkol Puangpetch

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

TABLE OF CONTENTS

Page

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

LIST OF TABLES

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

LIST OF FIGURES

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

CHAPTER I

INTRODUCTION

Background and rationale

Alveolar ridge, supported prosthesis, are continuously resorbed (1), resulting in loss of stability and pain in the tissue under prosthesis. Patients need to reline denture for good stability and retention (2-4)

Relining the denture can be done directly and indirectly. Direct hard relines are autopolymerizing hard reline materials. Using direct hard relines is quick, easy and do not need the laboratory procedures. Patients can immediately use the prosthesis. However, These materials have many disadvantages because of the reline odor, unpleasant taste and tissue irritations under the denture base due to residual monomers and higher temperatures during polymerization (5).

Adhesion failure of reline materials to denture base also causes accumulation of bacteria, color change (5-7) . It also reduces the strength of the denture base (5, 6, 8, 9). There are many methods to increase the bond strength of the reline materials and denture base, such as the surface grinding of the denture base (10), the abrasion with the surface particles (11, 12), and the application of various chemical agents such as methyl methacrylate (MMA) (5, 13-15), methylene chloride (16, 17), chloroform (5, 15, 17), acetone (15, 16), ethyl acetate (18), methyl formate (MF) (17), methyl acetate (MA) (17) and MF-MA (19, 20), etc. Chloroform and methylene chloride are a carcinogen (17). MMA is irritating and allergic (21).

Research questions

1. Does various chemical surface treatment affect on the flexural strength of the relined denture base material with the same hard reline materials?

2. Does the type of hard reline materials affect on the flexural strength of the relined denture base material with the same surface treatment condition?

Research objective

To evaluate the effect of MF-MA surface treatment on flexural strength between denture base and hard reline materials.

Research hypotheses

1. H_0: The flexural strength of relined denture base groups with various chemical surface treatments were not significantly different from that of the untreated surface group at the 95% confidence level.

H_1: the flexural strength of relined denture base groups with various chemical surface treatments were significantly different from that of the untreated surface group at the 95% confidence level.

2. H_0: There were not significantly different flexural strength between the relined denture base groups with various chemical surface treatments at the 95% confidence level.

H_1: There were significantly different flexural strength between the relined denture base groups with various chemical surface treatments at the 95% confidence level.

3. H_0: In the same chemical surface treatments, there is no significant difference on the flexural strength of the relined denture base groups with various hard reline materials at the 95% confidence level.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

H_1: In the same chemical surface treatments, there is a significant difference on the flexural strength of the relined denture base groups with various hard reline materials at the 95% confidence level.

4. H_0: In Tokuyama® Rebase II Fast groups with the same chemical surface treatments, there were not significantly different flexural strength between the relined denture base groups with hardener and without hardener treatments at the 95% confidence level.

H_1: In Tokuyama® Rebase II Fast groups with the same chemical surface treatments, there were significantly different flexural strength between the relined denture base groups with hardener and without hardener treatments at the 95% confidence level.

Scope of the research

1. This research is an in-vitro study
2. The three types of commercial hard reline materials used in this study are Unifast Trad®, Kooliner® and Tokuyama® Rebase II Fast.
3. A single investigator performed this study

Keywords

Acrylic denture base

Flexural strength

Hard reline materials

Methyl formate-methyl acetate

Methyl methacrylate

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Expected Benefits

1. To understand the flexural strength between denture base and hard reline materials after use various chemical surface treatment.
2. The results of this study can be used clinically in the selection of chemical agent to improve flexural strength between denture base and hard reline materials.

Conceptual Framework

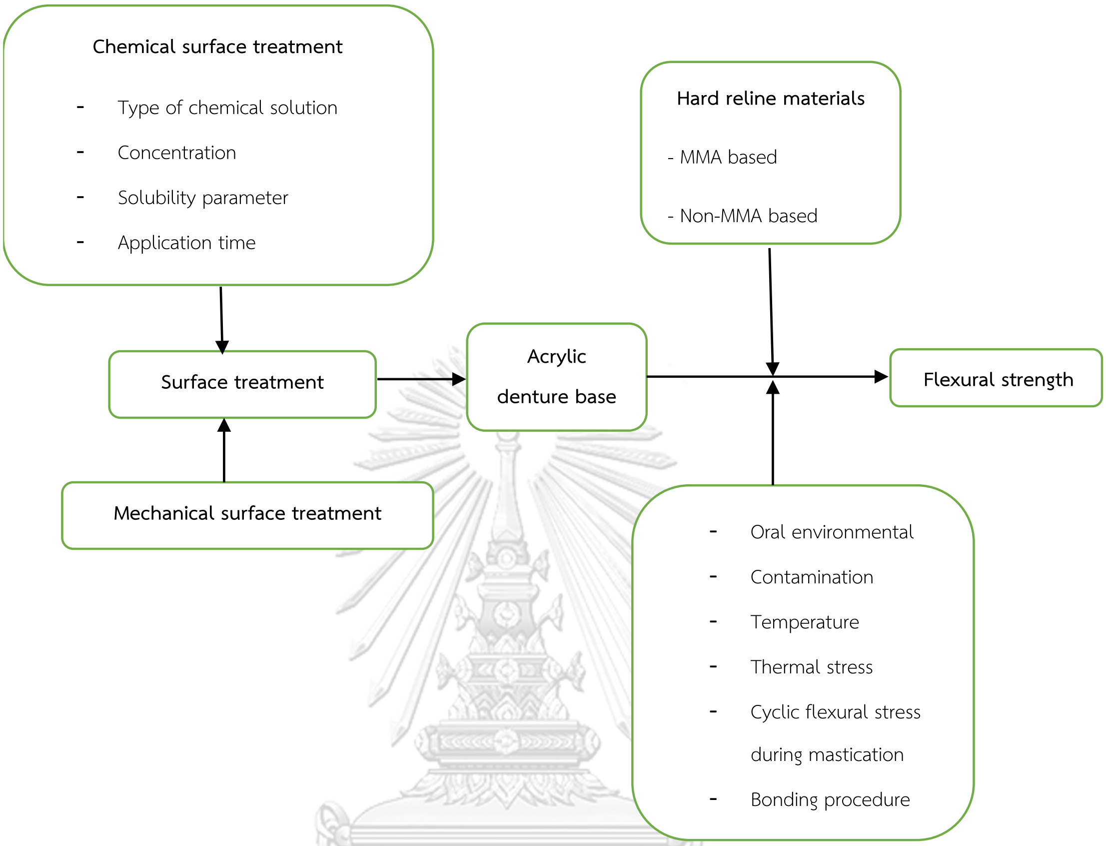

Figure 1 Conceptual Framework

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

CHAPTER II
LITERATURE REVIEW

Denture base polymers

Denture base can be classified according to their chemical composition and curing methods followed ISO 20795-1: 2013 (22) The classification is shown in table 1.

Table 1. Classification of denture base followed ISO 20795-1: 2013

Type	Class	Description
1	1	Heat-processing polymers, powder and liquid
1	2	Heat-processing (plastic cake)
2	1	Autopolymerised polymers, powder and liquid
2	2	Autopolymerised polymers (powder and liquid pour type resins)
3	-	Thermoplastic blank or powder
4	-	Light-activated materials
5	-	Microwave-cure materials

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

The chemical compositions of acrylic denture base materials are shown in table 2. Heat-polymerized acrylic resin is commonly used for denture base fabrication. The powder contains pre-polymerized poly(methyl methacrylate) (PMMA) resin and benzoyl peroxide. Benzoyl peroxide is a polymerization initiator. The liquid contains MMA monomer, hydroquinone, and glycol dimethacrylate. Hydroquinone is an inhibitor that prevents MMA polymerization during storage. Glycol dimethacrylate, the cross-linking agent, is incorporated into the growing polymer chains by unit two polymer chains. The polymerization of MMA in heat-polymerized acrylic resin is achieved by heat (23). The polymer forms a net-like structure that provides increased resistance to deformation.

Auto-polymerized acrylic resin is usually used as a reline or repair material of denture base and as a provisional restoration for fixed prosthesis. The addition of a tertiary amine to the denture base liquid allows the resin to auto-polymerize. Tertiary amine is an activator that causes decomposition of benzoyl peroxide and produces free radicals at room temperature. Because of the oxidation of the tertiary amine, the auto-polymerized acrylic resin generally has low color stability, but this can be minimized by the addition of stabilizing agents to prevent oxidation (24, 25).

Table 2. Composition of acrylic denture base materials (24)

Powder	Polymer	Poly(metyl metacrylate) beads
	Initiator	Benzoyl peroxide (approximately 0.5%)
	Pigments	Salts of cadmium or iron or organic dyes
Liquid	Monomer	Methyl methacrylate
	Cross-linking agent	Ethylene glycol dimethacrylate (approximately 10%)
	Inhibitor	Hydroquinone
	Activator*	N *N'*-dimethyl-*p*-toluidine (approximately 1%)

* Only in self-curing materials.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Degree of conversion of heat-polymerized acrylic denture base

Each monomer has at least one chemical group that participates in the polymerization reaction. However, not all monomers may be able to react completely, and any unreacted monomer is called *residual monomer*. The number of polymerized monomer was calculated by the *degree of conversion* (23). Polymers with high degrees of conversion have low levels of residual monomer (23). Proper processing techniques minimize residual monomer content in denture bases and keep residual monomer in the range of 1–3% which is well tolerated by most individuals (26). As good as, ISO specification 20795-1: 2013 are determined the maximum residual monomer of denture base type 1, 3, 4 and 5 not more than 2.2% but type 2 (auto-polymerized acrylic resin) not more than 4.5% (22). Residual monomer may diffuse from acrylic resin resulting in irritation or allergic side effects. For acrylic resins to induce a primary irritation or sensitization, free monomer must be leached out. There are well-documented reports of both hypersensitivity and local irritation caused by methyl methacrylate monomer (27).

The residual monomer was calculated according to the equation:

$$\text{Residual monomer (\% mass fraction)} = \frac{mMMA}{mSAMPLE} x\ 100$$

When $mMMA$ is the total quantity of MMA in the sample solution, in micrograms and $mSAMPLE$ is the mass of sample, in micrograms (22).

Denture lining materials (24, 28)

Denture lining materials can be divided into three groups:

1. Hard reline materials;
2. Tissue conditioners;
3. Soft lining materials.

Hard reline materials are used to add on the fitting surface of a denture base because of reduced resorption of the residual alveolar ridge and improved retention of the denture. The criteria for relining are:

- poor retention or stability,
- collapse of the vertical dimension of the occlusion,
- degradation of the denture base,
- lack of denture extension into muco-buccal fold areas.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

The reline can be achieved either with an auto-polymerized acrylic resin at the chairside, or heat-polymerized acrylic by sent to a dental laboratory. The auto-polymerized acrylic reline resins were two types, with constituents as listed in table 3. The reason for using the second type of reline material is that MMA can be very irritant to soft tissue and sensitize the patient. Poly(ethyl methacrylate) (PEMA) and butyl methacrylate are less irritating to the patient, but have the disadvantage that they cause a reduction in the glass transition temperature (T_g) which increases the possibility of dimensional instability.

Table 3. Composition of typical hard reline materials (24).

Type 1	*Powder*		
		Polymer beads	Poly(methyl methacrylate)
		Initiator	Benzoyl peroxide
	Liquid		
		Monomer	Methyl methacrylate
		Plasticizer	Di-*n*-butyl phthalate
		Chemical activator	Tertiary amine
Type 2	*Powder*		
		Polymer beads	Poly(ethyl methacrylate)
		Initiator	Benzoyl perroxide
	Liquid		
		Monomer	Butyl methacrylate

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

Cross-linking agent	Di-methacrylate
Chemical activator	Tertiary amine

Factors affected on bonding to acrylic denture base materials

The factors affected on bond strength of denture base and denture reline material had been investigated. Many studies found that type of denture base, type of denture reline material, type of surface treatment affected on bond strength (6, 8, 16, 25, 29)

Type of denture base

Poly(methyl methacrylate) resins have been preferred as denture base resins because of their physical and esthetic properties as well as the material's availability, reasonable cost, and ease of manipulation (25). In previous study revealed that high cross-linked denture base or denture teeth polymers restrict the penetration of monomers because of high density polymer network can cause decreasing of bond strength between denture base and denture relining material (8, 16).

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Type of denture relining materials

Differences of components in a denture relining material affected on bond strength. In previous studies were found that MMA based reline resin had better adhesion compared with non-MMA-based reline resin because of lower molecular weight of MMA monomer in the denture lining material. The monomers with lower molecular weight can better diffuse, penetrate and form an interpenetrating polymer network than the monomers with high molecular weight (6).

A weak bond strength of relined denture base could accumulate bacteria, promote staining and result in complete delamination of denture base and denture reline materials. In addition, the relined denture must exhibit satisfactory strength to prevent fracture during function (7). Consequently, the adhesion between denture base and reline materials is necessary in the success of the relining procedure (5) .

Surface treatment

Surface treatment of the denture base before relining has been suggested to improve the bond strength of denture base and denture reline material. This treatment can be classified into mechanical and chemical surface treatment.

Mechanical surface treatment

The preparation of denture base with fine tungsten carbide bur also improves the bond strength of denture base and reline material by producing a rough surface (10). However, the polishing with 240-grit silicone carbide paper and air abrasion with 50-µm aluminum oxide particles prior relining did not improve the bond strength between some groups of denture reline materials and denture base acrylic resin (11).

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Chemical surface treatment

Takahashi et al (2001) revealed that the application of various chemical agents could improve the bond strength between denture base and relining materials (11). The action of nonpolymerizable solvents such as dichloromethane are dissolving and swelling the surface layer of the denture base. This process promotes the diffusion of denture reline monomers and the formation of a more extensive interwoven polymer network (11).

Denture base or denture reline monomers are polymerizable solvents such as MMA and isobuthyl methacrylate monomers. The denture base or denture reline monomers can improves bond strength by dissolving the denture base (11), the penetration of monomers from reline materials into the denture base, and then polymerization with other monomer molecules in the reline material.

Manufacturing adhesive or bonding agent can improve the bond strength of the denture base and denture reline materials in comparison to untreated specimens. Thus, the manufacturer recommend to use bonding agent prior to relining. The various composition manufacturing adhesive or bonding agent of such as MMA (5, 11, 13) tetrahydrofurfuryl methacrylate (THFMA) (11), 1,6-hexa-nediol dimethacrylate (HDDMA) (11), acetone (5, 11). For example, Tetrahydrofurfuryl methacrylate (THFMA) in Triad bonding agent can increase viscosity of its mix with MMA. Acetone in GC bonding agent acts likely nonpolymerizable solvents (11).

Arima et al (1996) investigated the effect of resin surface primers for reline acrylic resins on the surface texture of denture base resin by use of scanning electron microscopy. The results of this study suggest the importance of denture base resin surface treatment with the related primer before relining the denture base. Primers that consist of solvents may dissolve the surface of the denture base and promote penetration of the reline acrylic resin into the denture base, these reactions may result in formation of a mixed layer of reline acrylic resin and denture base resin. (29)

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

In addition, factors that need to be considered in selecting chemical surface treatment to improve bond strength are solubility parameter and polarity.

Solubility parameter and polarity

Asmussen and Peutzfeldt (2001) found that the dissolution efficiency depend on relative closeness of solubility parameter and polarity of PMMA and the solvents (17). The solubility parameter and polarity of solvent this study are presented in Table 4 (30).

Table 4. The solubility parameter and polarity of acrylic denture base and solvents in this study (30)

Name	Solubility parameter ($MPa^{1/2}$)	Polarity
Poly(methyl methacrylate)	18.3	Methyl ester
Methyl methacrylate	18	Methyl ester
Methyl formate	20.9	Methyl ester
Methyl acetate	19.6	Methyl ester
Ethyl acetate	18.2	Ethyl ester
Acetone	19.7	Ketone

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Chemical agents that have been used to improve the denture base include MMA, chloroform, methylene chloride, acetone, ethyl acetate, MF and MA.

Methyl methacrylate

Methyl methacrylate ($CH_2=C(CH_3)COOCH_3$) is a clear colorless, low viscosity liquid with a boiling point of 100.3 °C and a distinct odor exaggerated by a relatively high vapor pressure at room temperature (24). The structure formula of methyl methacrylate is shown in Figure 1.

The application of MMA monomer and chloroform provided higher transverse bond strength compared with the application of acetone and isobuthyl methacrylate (5). In addition, adequate wetting time of MMA (for 180 seconds) is important to increase the bond strength of repaired acrylic resin because of MMA dissolves the heat-polymerized PMMA surface (13).

However, MMA has the potential adverse effects such as mucosal irritation or allergic reaction to patients and dentists. (21)

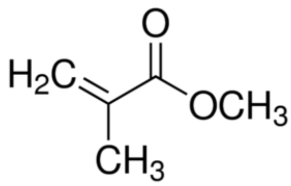

Figure 2. Structural formula of methyl methacrylate

Chloroform and Methylene chloride

The use of methylene chloride (CH_2Cl_2) or acetone prior to denture base repair can improve the shear bond strength of denture base (16). In addition, the treating the fractured surface of denture base with chloroform ($CHCl_3$) before repair denture base can improve the transverse strength (31). However, chloroform and methylene chloride are carcinogens which should not be used in human (32, 33).

Acetone

Acetone (CH_3-CO-CH_3) is a clear, colorless liquid. It is used as a solvent for fats, oils, waxes, resins, plastics and varnishes for making other chemicals and nail polish remover (34), the structural formula of acetone is shown in Figure 2.

Acetone in manufacturing bonding agent acts likely nonpolymerizable solvent to improve the bond strength of denture base and reline materials (11).

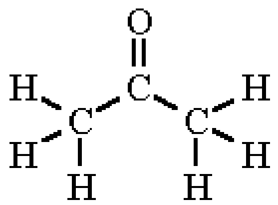

Figure 3. Structural formula of acetone

Ethyl acetate

Ethyl acetate ($CH_3COOC_2H_5$) is a clear colorless liquid. It is used in glues, nail polish removers, decaffeinating tea and coffee (35), the structural formula of ethyl acetate is shown in Figure 3.

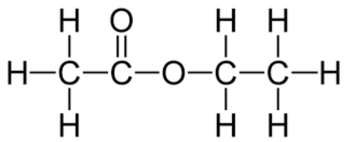

Figure 4. Structural formula of ethyl acetate

Acetone and ethyl acetate are presented in the composition of Tokuyama® Rebase II Fast adhesive which is material in this study.

Methyl formate and Methyl acetate

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

Methyl formate ($HCOOCH_3$) or methyl methanoate, is the methyl ester of formic acid. It is a colorless liquid with an ethereal odor, high vapor pressure, and low surface tension (36, 37). The structural formula of methyl formate is shown in Figure 4.

Methyl acetate (CH_3COOCH_3) or methyl ethanoate, is a carboxylate ester. It is a flammable liquid. It is occasionally used as a solvent, being weakly polar and lipophilic, but its close relative ethyl acetate is a more common solvent being less toxic and less soluble in water (38, 39). The structural formula of methyl formate is shown in Figure 5.

Asmussen et al., 2000 (17) found that methyl formate and methyl acetate improved the bond strength between the hard reline materials and the denture base, which is close to methylene chloride and higher than ethyl acetate.

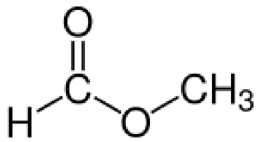

Figure 5. Structural formula of methyl formate

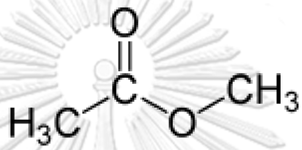

Figure 6. Structural formula of methyl acetate

Methyl formate- methyl acetate (MF-MA)

Thunyakitpisal et al., 2011 (19), found that the application of MF-MA solution at the denture base surface for 15 seconds before repairing the denture could significantly increase the flexural strength. In addition, Osathananda and Wiwatwarrapan, 2016 (20) also found that the application of MF-MA solution increased the shear strength between the hard reline and denture base compared to the adhesive which is recommended by the manufacturer.

CHULALONGKORN UNIVERSITY

There are many types of hard reline materials used in Thailand such as Kooliner®, Tokuyama® Rebase II Fast, Unifast Trad®. No research has not been shown on the effect of this MF-MA surface treatment of the denture base and hard reline materials on the flexural strength.

This study aims to evaluate the effect of MF-MA surface treatment on the flexural strength between the denture base and hard reline materials.

CHAPTER III

METHODOLOGY

Target population

Heat -polymerized acrylic resin

Sample

Relined denture base 180 specimens

Table 5. The product names and manufacturers of samples use in this study.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Product name	Materials	Manufacturer
Meliodent®	Powder:PMMA Liquid: MMA	Kulzer, Germany
Kooliner®	Powder:PEMA Liquid: IBMA	GC America, USA
Tokuyama® Rebase II Fast	Powder:PEMA Liquid: AAEMA, 1,9-NDMA	Tokuyama Dental Corp, Japan
Unifast Trad®	Powder:PMMA Liquid: MMA	GC America, USA
Adhesive-Tokuyama® Rebase II Fast	ethyl acetate& acetone	Tokuyama Dental Corp, Japan
Methyl formate	Methyl formate	Merck Schuchardt OHG, Germany
Methyl acetate	Methyl acetate	Merck KGaA, USA

PMMA, Poly(methyl methacrylate); MMA, Methyl methacrylate; PEMA, Poly(ethyl methacrylate); IBMA, Isobutyl methacrylate; AAEMA, 2-(Acetoacetoxy) ethyl methacrylate; 1,9-NDMA, 1,9 Nonanediol dimethacrylate.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Instruments

1. Heat-polymerized curing unit 'EWL 5518' (Kavo, Germany)
2. Hydraulic flask pressure 'EWG 5414' (Kavo, Germany)
3. Universal testing machine (SHIMADZU, EZ-S 500N model, Japan)
4. Automatic grinding and polishing unit (Minitech 233, Metallography India, Maharashtra, India)

5. Digital Vernier caliper (Mitutoyo, Japan)
6. Incubator 37°C (Contherm Scientific Ltd., New Zealand)
7. Hanau flask
8. Rectangular stainless-steel mold
9. Teflon sheet
10. Dental stone
11. Metallographic grinding paper P500 and P1200 (TOA, Thailand)

Sample preparation

One-hundred eighty specimens of heat-cured acrylic denture base (Meliodent®) (64x10x2 mm) were prepared in a denture flask (Figure 6 [a]) as recommended from ISO 20795-1 (2013). The specimens were finished with 500-grit silicon carbide paper using an automatic grinding and polishing unit (Minitech 233, Metallography India, Maharashtra, India).

The specimens were randomly divided into groups as shown in Table 6, and then were placed in split metal mold (64x10x3.3 mm) (Figure 6 [b]) and applied the chemical surface treatment. For MMA surface treatment, Unifast Trad® (MMA) liquid was applied for 180 s (by brush 1 time per 5 seconds) and then wait for 30 seconds to evaporate. For MF-MA surface treatment, MF-MA solution (25:75 by volume) was applied for 15 s (by brush 1 time per 5 seconds) and then wait for 30 seconds to evaporate. For adhesive surface treatment, Tokuyama® Rebase II Fast adhesive was applied following the manufacturer instructions. After that, the specimens were relined with a relining material (Figure 6 [c])

The specimens were randomly divided into groups as shown in Table 6, and then were placed in split metal mold (64x10x3.3 mm) (Figure 6 [b]) and relined with a relining material (Figure 6 [c]).

The specimens were randomly divided into 18 groups:

- Group I, II, III relined with Unifast trad®.

- Group IV V, VI relined with Kooliner®;
- Group VII, VIII, IX relined with Tokuyama® Rebase II Fast (without adhesive, with hardener);
- Group X, XI, XII relined with Tokuyama® Rebase II Fast (with adhesive and hardener);
- Group XIII, XIV, XV relined with Tokuyama® Rebase II Fast (without adhesive and hardener);
- Group XVI, XVII, XVIII relined with Tokuyama® Rebase II Fast (with adhesive, without hardener);

The reline surface of specimens were finished with a 500-grit new silicon carbide paper using an automatic grinding and polishing unit (Minitech 233, France) and stored in a water at 37±1°C for 48±2 hrs. The flexural strength was measured by universal testing machine (SHIMADZU, EZ-S 500N model, Japan). The force was increased on the loading plunger from zero, uniformly, using a constant displacement rate of 5±1 mm/min and span of 50 mm and 500 N load cell until the specimen breaks (Figure 6 [d]). Flexural strength (MPa) was calculated using the following equations:

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

$$\delta = \frac{3Fl}{2bh^2}$$

Where δ =flexural strength (MPa)

F = the load (N) at fracture

l = the distance between supports (mm)

b = mean of specimen width (mm)

h = mean of specimen height (mm)

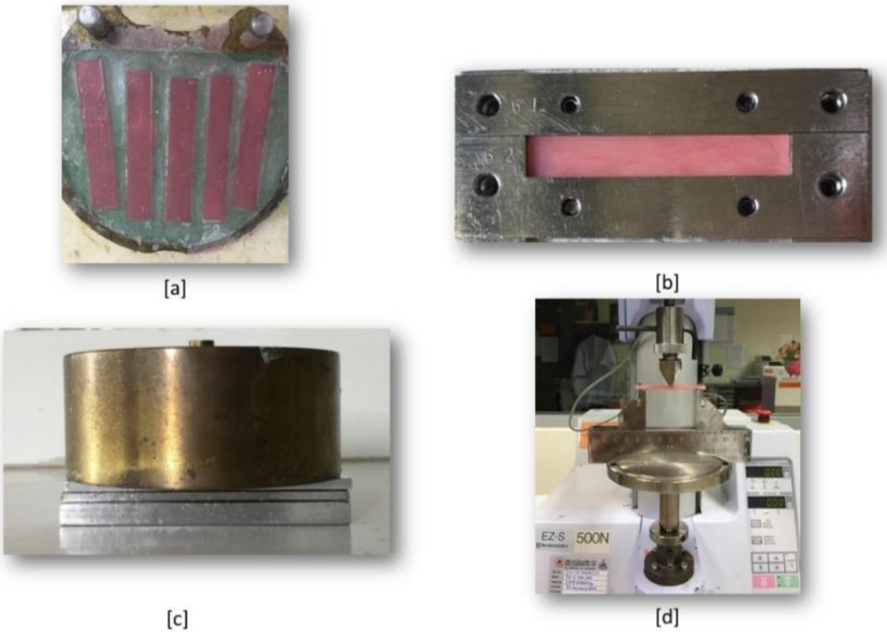

Figure 7. Specimen preparation. [a] Heat-cured acrylic denture base (64x10x2 mm) were prepared in a denture flask. [b] The specimens were placed in split metal mold (64x10x3.3 mm), apply surface treatment agent and relined with a relining material. [c] pressed lightly topped with 1 kg iron. [d] flexural strength test.

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

Table 6. Description of experimental groups (N=10)

Group	Reline materials	Surface treatment			Manufacturing hardener
		MMA 180 s	MF-MA 15 s	Manufacturing adhesive	
I	Unifast trad®	-	-	-	-
II	Unifast trad®	+	-	-	-
III	Unifast trad®	-	+	-	-
IV	Kooliner®	-	-	-	-
V	Kooliner®	+	-	-	-
VI	Kooliner®	-	+	-	-

VII	Tokuyama® Rebase II Fast	-	-	-	+
VIII	Tokuyama® Rebase II Fast	+	-	-	+
IX	Tokuyama® Rebase II Fast	-	+	-	+
X	Tokuyama® Rebase II Fast	-	-	+	+
XI	Tokuyama® Rebase II Fast	+	-	+	+
XII	Tokuyama® Rebase II Fast	-	+	+	+
XIII	Tokuyama® Rebase II Fast	-	-	-	-
XIV	Tokuyama® Rebase II Fast	+	-	-	-
XV	Tokuyama® Rebase II Fast	-	+	-	-
XVI	Tokuyama® Rebase II Fast	-	-	+	-
XVII	Tokuyama® Rebase II Fast	+	-	+	-
XVIII	Tokuyama® Rebase II Fast	-	+	+	-

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Statistical analysis

The data were analyzed using SPSS software version 22.0 (SPSS Inc., Chicago, IL, USA). The results were statistically analyzed by two-way ANOVA (group I-IX) (Type of reline: Unifast trad®, Kooliner®, Tokuyama® Rebase II Fast ; Surface treatment: untreat, MMA, MF-MA) and one-way ANOVA (group I-XVIII, the groups in each row and each column) If the significant differences were found, the mean flexural strengths of the groups were compared using Tukey's HSD Post-hoc test at a 95% confidence level. For Tokuyama® Rebase II Fast, the data were analyzed by three-way ANOVA (Hardener: with and without Hardener; Manfacuture Adhesive: with and without adhesive; Surface treatment: untreat, MMA, MF-MA)

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

CHAPTER 4
RESULTS

Result

The mean flexural strengths and standard deviation of each group (n=10) of Unifast Trad®, Kooliner®, Tokuyama® Rebase II Fast with Hardener and Tokuyama® Rebase II Fast without Hardener, respectively were presented in Table 7.

Table 7. The mean flexural strength with standard deviation of each reline material and surface treatment.

Surface treatment	Reline materials			
	Unifast Trad®	Kooliner®	Tokuyama® Rebase II with hardener	Tokuyama® Rebase II without hardener
Control	$79.56 \pm 2.35^{a, A}$	$72.28 \pm 2.47^{a, B}$	$60.05 \pm 2.45^{a, C}$	$60.18 \pm 2.52^{a, C}$
MMA	$88.94 \pm 3.72^{b, A}$	$76.42 \pm 3.18^{b, B}$	$64.60 \pm 2.22^{b, C}$	$64.95 \pm 1.99^{b, C}$
MF-MA	$97.53 \pm 2.36^{c, A}$	$81.09 \pm 2.17^{c, B}$	$71.97 \pm 2.48^{c, C}$	$72.64 \pm 1.42^{c, C}$
Adhesive	-	-	$66.89 \pm 1.54^{b, A}$	$65.70 \pm 2.63^{b, A}$
MMA+Adhesive	-	-	$71.99 \pm 2.39^{c, A}$	$71.52 \pm 2.48^{c, A}$
MFMA+Adhesive	-	-	$76.32 \pm 2.88^{d, A}$	$77.41 \pm 2.87^{d, A}$

****Same uppercase letter indicates no significant difference between the group in each row (p>0.05)*

****Same lowercase letter indicates no significant difference between the group in each column (p>0.05)*

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

The results were shown that all data were normal distributed in all groups (*p*>0.05) (Table 10 in appendix). The results of two-way ANOVA of Group I-IX (Table 8) were showed that the surface treatment and type of reline materials affected on the flexural strength ($p < 0.05$). There is an interaction effect on the flexural strength between the two factors of hard reline materials and the surface treatments ($p<0.05$).

Table 8. Two-way ANOVA of hard reline materials and the surface treatments (For Tokuyama® rebase II Fast = without hardener).

Source	Type III sum of squares	df	Mean square	F	P
Corrected model	10568.714[a]	8	1321.089	204.365	< 0.005
Intercept	534529.776	1	534529.776	82688.690	< 0.005
Product	7775.142	2	3887.571	601.385	< 0.005
SurfaceTx	2569.490	2	1284.745	198.743	< 0.005
Product*SurfaceTx	224.082	4	56.021	8.666	< 0.005
Error	523.613	81	6.464		
Total	545622.103	90			
Corrected total	11092.327	89			

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

For each material (Table 7), the flexural strength of surface treatment groups were significantly higher than that of the control group ($p<0.05$). The MF-MA treated group also had significantly higher flexural strength than the MMA treated group in each hard reline material ($p<0.05$).

For the same surface treatment (Table 7), the flexural strength of Unifast Trad® was significantly higher than that of Kooliner® ($p<0.05$), and the flexural strength of Kooliner® also was significantly higher than that of Tokuyama® Rebase II with and without hardener ($p<0.05$), respectively.

For Tokuyama® Rebase II with and without hardener, The results of three-way ANOVA (Table 9) were showed that the surface treatment and manufacturing adhesive affect on flexural strength (*p*<0.05) but the hardener do not affect on flexural strength. There is no interaction between hardener-surface treatment, hardener-adhesive, surface treatment-adhesive (*p*>0.05). There is no interaction between hardener-surface treatment-adhesive (*p*>0.05).

Table 9. Three-way ANOVA analysis of Tokuyama® Rebase II Fast.

Source	Type III sum of squares	df	Mean square	F	P
Corrected model	3693.750[a]	11	335.795	60.193	< 0.005
Intercept	566148.476	1	566148.476	101484.240	< 0.005
Hardener	.273	1	.273	.049	> 0.005
SurfaceTx	2600.040	2	1300.020	233.033	< 0.005
Adhesive	1046.189	1	1046.189	187.533	< 0.005
Hardener*SurfaceTx	10.401	2	5.201	.932	> 0.005
Hardener*Adhesive	2.431	1	2.431	.436	> 0.005
SurfaceTx*Adhesive	30.429	2	15.215	2.727	> 0.005
Hardener*SurfaceTx *Adhesive	3.987	2	1.993	.357	> 0.005
Error	602.498	108	5.579		
Total	570444.724	120			
Corrected total	4296.248	119			

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

For Tokuyama® Rebase II with and without hardener (Table 7), there were no significant differences in the mean flexural strength between the groups of with and without hardener (*p*>0.05). Additional surface treatment (MMA, and MF-MA) with the adhesive groups significantly increased the flexural strength compared with the groups with only using the manufacturing adhesive. (*p*<0.05). The MF-MA+Adhesive treated group also had significantly higher flexural strength than the other groups (*p*<0.05). The orders of the flexural strength of various groups were MF-MA+Adhesive>MMA+Adhesive, MF-MA>Adhesive, MMA>Control, respectively.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

CHAPTER 5
DISCUSSION AND CONCLUSION

Discussion

In this study, the flexural strength was used to compare the bond strength of relined denture base with the difference surface treatment and hard reline materials. Vallittu *et al.*, 1994 concluded that the MMA wetting time of 180 seconds was recommended to strengthen the repaired acrylic resin (13). In addition, Thunyakitpisal *et al*., (2011) was found that the application of MF-MA solution at the denture base for 15 seconds before the repairing could significantly increase the flexural strength (19). For these reason, the surface treatment with MMA 180 seconds and MF-MA for 15 seconds were used to improve the bonding between hard reline and denture base materials in this study. Unifast® and Kooliner® do not have any adhesive from the manufacturer, thus the groups of these reline materials were not applied the adhesive.

For each hard reline material, the mean flexural strength of MF-MA treated groups were significantly higher than that of MMA-treated group and the flexural strength of MMA-treated groups also were significantly higher than that of the untreated groups. ($p<0.05$) The bonding mechanism of relined denture base was explained that the solvents or monomers in the surface treatment dissolved and swelled the surface of denture base and evaporated causing of swellen surface layers. Next, the monomer in the reline material diffused and penetrated into the pores of the denture base and polymerized form an interpenetrating polymer network (40). Three solvents were used for the denture base surface treatment (MF-MA, MMA, and Tokuyama Rebase II adhesive (ethyl acetate and acetone)). The dissolution efficiency can be explained by the relative closeness of solubility parameters and polarities of

PMMA and the solvents. The solubility parameters of various solvents are closed to the acrylic denture base (PMMA, 18.3 $MPa^{½}$). These solubility parameters of MMA, MF, MA, ethyl acetate, and acetone are 18.0, 20.9, 19.6, 18.2 and 19.7 $MPa^{½}$, respectively. Based on these results, the first null hypothesis was rejected.

For each hard reline material, the mean flexural strength of MF-MA treated group was significantly higher than that of MMA treated group and manufacturer adhesive treated group (for Tokuyama® Rebase II Fast) (p<0.05) MF, MA and MMA have similar polarities due to their methyl ester groups that enhance their ability to soften the acrylic denture base while the other solvents have different functional groups. Acetone has ketone group. Ethyl acetate is being ethyl ester. The dissimilar polarity of ethyl acetate and acetone to PMMA is likely to bring these compounds out of the range of effective solubility. In addition, the molecular weight of solvent has an effect on the softening efficacy which lower molecular weight promotes the faster kinetics of diffusion. MF (60.05 Da), MA (74.08 Da), acetone (58.08 Da), and ethyl acetate (88.11 Da) have lower molecular weight than MMA (100.12 Da) that promotes greater solubility to the denture base (41).

The boiling point of solvents also affects to the bonding process that lower boiling point of solvent causes an easier evaporation and takes less chair-time. Methyl formate (31.8°C) has the least boiling point compared to the other solvents. Methyl acetate (56.9°C) and acetone (57°C) have a similar boiling point. Ethyl acetate and MMA have a higher boiling point of 77.1°C, 101°C, respectively. A higher molecular weight and boiling point of MMA might be provided lower solubility to the acrylic denture base material compared to MF-MA solution. Ethyl acetate and acetone (in Tokuyama® Rebase II Fast adhesive) has similar solubility parameter compared to PMMA but they have different functional groups in their chemical structure. Besides, ethyl acetate has a higher molecular weight and boiling point compared to MF-MA solution and acetone. Acetone has many requirements to promote PMMA dissolution similar to MF-MA

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

except the different functional group in chemical structure. The second null hypothesis was rejected

For the same surface treatment, the flexural strength of Unifast Trad® relined groups was significantly higher compared with those of the Kooliner® and Tokuyama Rebase II relined groups. The monomer (in liquid part) with lower molecular weight can diffuse and penetrate and form an interpenetrating polymer network better than that with high molecular weight. The Unifast Trad® liquid contains MMA (100.12 Da) that are lower in molecular weight compared with the IBMA (142.20 Da) in Kooliner, or AAEMA (214.21 Da) and 1,9 NDMA (296.40 Da) in Tokuyama® Rebase II Fast (42). The third null hypothesis was also rejected.

For Tokuyama® rebase II Fast, there was no significant difference on the flexural strength between Tokuyama® rebase II Fast with and without hardener. Yatabe M et al. (2001) reported that reducing agent help removing oxygen from the free radical on the surface oxygen-inhibited layer of the reline material. Thus, allow the polymerization to continue and the unpolymerized layer was further cured after immerse in reducing agent solution. The flexural strength of the cross-linked reline material was increase significantly after immerse for 15 minutes (43). However, the previous study have found in contrast of this study, it may be explained by the short duration of immerse for 3 minutes. Thus, no different in flexural strength of Tokuyama® rebase II Fast with and without hardener. The last null hypothesis was accepted.

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

Conclusion

Surface treatment with MF-MA solution significantly increases the flexural strength of relined denture base. This study suggests the application of MF-MA solutions for 15 s before relining procedure to improve the flexural strength between denture base and hard reline materials.

REFERENCES

1. Tallgren A. The continuing reduction of the residual alveolar ridges in complete denture wearers: a mixed-longitudinal study covering 25 years. ***J Prosthet Dent***. 1972;27(2):120-32.

2. Reis JM, Vergani CE, Pavarina AC, Giampaolo ET, Machado AL. Effect of relining, water storage and cyclic loading on the flexural strength of a denture base acrylic resin. ***J Dent***. 2006;34(7):420-6.

3. Takahashi Y, Kawaguchi M, Chai J. Flexural strength at the proportional limit of a denture base material relined with four different denture reline materials. ***Int J Prosthodont***. 1997;10(6):508-12.

4. Aydın AK, Terzioğlu H, Akınay AE, Ulubayram K, Hasırcı N. Bond strength and failure analysis of lining materials to denture resin. ***Dent Mater***. 1999;15(3):211-8.

5. Leles CR, Machado AL, Vergani CE, Giampaolo ET, Pavarina AC. Bonding strength between a hard chairside reline resin and a denture base material as influenced by surface treatment. ***J Oral Rehabil***. 2001;28(12):1153-7.

6. Mutluay MM, Ruyter IE. Evaluation of adhesion of chairside hard relining materials to denture base polymers. ***J Prosthet Dent***. 2005;94(5):445-52.

7. Arena C, Evans DB, Hilton TJ. A comparison of bond strengths among chairside hard reline materials. ***J Prosthet Dent*** 1993;70(2):126-31.

8. Takahashi Y, Chai J. Shear bond strength of denture reline polymers to denture base polymers. ***Int J Prosthodont***. 2001;14(3):271-5.

9. Chai J, Takahashi Y, Kawaguchi M. The flexural strengths of denture base acrylic resins after relining with a visible-light-activated material. ***Int J Prosthodont***. 1998;11(2):121-4.

10. Baig MR, Ariff FTM, Yunus N. The effect of bur preparation on the surface roughness and reline bond strength of urethane dimethacrylate denture base resin. ***Indian J Dent Res***. 2011;22(2):210-2.

11. Takahashi Y, Chai J. Assessment of shear bond strength between three denture reline materials and a denture base acrylic resin. ***Int J Prosthodont***. 2001;14(6):531-5.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

12. Memarian M, Shayestehmajd M. The effect of chemical and mechanical treatment of the denture base resin surface on the shear bond strength of denture repairs. ***Rev Clin Pesq Odontol***. 2009;5(1):11-7.

13. Vallittu PK, Lassila VP, Lappalainen R. Wetting the repair surface with methyl methacrylate affects the transverse strength of repaired heat-polymerized resin. ***J Prosthet Dent***. 1994;72(6):639-43.

14. da Cruz Perez LE, Machado AL, Canevarolo SV, Vergani CE, Giampaolo ET, Pavarina AC. Effect of reline material and denture base surface treatment on the impact strength of a denture base acrylic resin. ***Gerodontology***. 2010;27(1):62-9.

15. Vojdani M, Rezaei S, Zareeian L. Effect of chemical surface treatments and repair material on transverse strength of repaired acrylic denture resin. ***Indian J Dent Res*** 2008;19(1):2-5.

16. Sarac YS, Sarac D, Kulunk T, Kulunk S. The effect of chemical surface treatments of different denture base resins on the shear bond strength of denture repair. ***J Prosthet Dent***. 2005;94(3):259-66.

17. Asmussen E, Peutzfeldt A. Substitutes for methylene chloride as dental softening agent. ***Eur J Oral Sci*** 2000;108(4):335-40.

18. Shimizu H, Kakigi M, Fujii J, Tsue F, Takahashi Y. Effect of surface preparation using ethyl acetate on the shear bond strength of repair resin to denture base resin. ***J Prosthodont***. 2008;17(6):451-5.

19. Thunyakitpisal N, Thunyakitpisal P, Wiwatwarapan C. The effect of chemical surface treatments on the flexural strength of repaired acrylic denture base resin. ***J Prosthodont***. 2011;20(3):195-9.

20. Osathananda R, Wiwatwarrapan C. Surface treatment with methyl formate–methyl acetate increased the shear bond strength between reline resins and denture base resin. ***Gerodontology***. 2016;33(2):147-54.

21. Leggat PA, Kedjarune U. Toxicity of methyl methacrylate in dentistry. ***Int Dent J***. 2003;53(3):126-31.

22. International Organization for Standardization. Denture base polymers- Part1: denture base polymers 20795-1(2013): Genewa,Switzerland

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

23. Powers JM, Wataha JC. Dental materials: properties and manipulation. 9th ed. St. Louis, Missouri: Mosby Elsevier; 2008 p. 288-99.

24. McCabe JF, Walls AWG. Applied dental materials. 9th ed. Oxford: Blackwell Publishing; 2008 p. 112-8.

25. Anusavice KJ. Phillip's science of dental material. 11th ed. Philadelphia: WB Saunders; 2003 p. 107-8.

26. Powers JM, Sakaguchi RL. Craig's restorative dental materials. 13th ed. St. Louis, Missouri: Mosby Elsevier; 2012 p. 191-2.

27. Bartoloni JA, Murchison DF, Wofford DT, Sarkar NK. Degree of conversion in denture base materials for varied polymerization techniques. ***J Oral Rehabil***. 2000;27(6):488-93.

28. van Noort R. Introduction to dental materials. 3rd ed. Philadelphia: Mosby Elsevier; 2007 p. 23-9.

29. Arima T, Nikawa H, Hamada T. Composition and effect of denture base resin surface primers for reline acrylic resins. ***J Prosth Dent***. 1996;75(4):457-62.

30. Grulke EA. Polymer Handbook: Solubility parameter values. 4th ed. In: Brandrup J, Immerut EH, Grulke EA., editor. New York: Wiley; 1999 p.688-705.

31. Shen C, Colaizzi FA, Birns B. Strength of denture repairs as influenced by surface treatment. ***J Prosthet Dent***. 1984;52(6):844-8.

32. Groger W, Grey T. Effect of chloroform on the activities of liver enzymes in rats. ***Toxicology***. 1979;14(1):23-38.

33. Kumagai S, Kurumatani N, Arimoto A, Ichihara G. Cholangiocarcinoma among offset colour proof-printing workers exposed to 1, 2-dichloropropane and/or dichloromethane. ***Occup Environ Med***. 2013;70(7):508-10.

34. Health NJDo. Hazardous Substance Fact Sheet: Acetone 2011 [cited 2019 20 May]. Available from: https://www.nj.gov/health/eoh/rtkweb/documents/fs/0006.pdf.

35. Health NJDo. Hazardous Substance Fact Sheet: Ethyl acetate 2016 [cited 2019 20 May]. Available from: https://www.nj.gov/health/eoh/rtkweb/documents/fs/0841.pdf.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

36. Merckmilipore[Internet]. Methyl-formate [cited 2018 25 May]. Available from: http://www.merckmillipore.com/TH/en/product/Methyl-formate,MDA_CHEM-800889.

37. Chemicalland21.com[Internet]. Methyl formate [cited 2018 25 May]. Available from: http://www.chemicalland21.com/industrialchem/organic/METHYL%20FORMATE.htm.

38. Merckmillipore[Internet]. Methyl-acetate [cited 2018 25 May]. Available from: http://www.merckmillipore.com/TH/en/product/Methyl-acetate,MDA_CHEM-809711.

39. Chemicalland21.com[Internet]. Methyl acetate [cited 2018 25 May]. Available from: http://www.chemicalland21.com/industrialchem/solalc/METHYL%20ACETATE.htm.

40. Vallittu PK, Ruyter IE. Swelling of poly (methyl methacrylate) resin at the repair joint. ***Int J Prosthodont*** 1997;10(3):254-8.

41. Evchuk IY, Musii RI, Makitra RG, Pristanskii RE. Solubility of polymethyl methacrylate in organic solvents. ***Russ J Appl Chem***. 2005;78(10):1576-80.

42. Asmussen E, Uno S. Solubility parameters, fractional polarities, and bond strengths of some intermediary resins used in dentin bonding. ***J Dent Res***. 1993;72(3):558-65.

43. Yatabe M, Seki H, Shirasu N, Sone M. Effect of the reducing agent on the oxygen-inhibited layer of the cross-linked reline material. ***J Oral Rehabil***. 2001;28(2):180-5.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

APPENDIX

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Table 10. Analysis of the data distribution.

Tests of Normality

	group	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Maxstress	No Tx Unifast	.150	10	.200*	.968	10	.876
	MMA Unifast	.147	10	.200*	.968	10	.869
	MFMA	.136	10	.200*	.938	10	.534
	No Tx Kooliner	.216	10	.200*	.949	10	.656
	MMA Kooliner	.130	10	.200*	.965	10	.843
	MFMA Kooliner	.207	10	.200*	.894	10	.190
	No Tx Rebase+H	.178	10	.200*	.933	10	.483
	MMA Rebase+H	.222	10	.175	.937	10	.520
	MFMA Rebase+H	.238	10	.116	.868	10	.094
	Ad Rebase+H	.231	10	.140	.822	10	.027
	MMA Ad Rebase+H	.181	10	.200*	.867	10	.093
	MFMA Ad Rebase+H	.134	10	.200*	.968	10	.869
	No Tx Rebase-H	.179	10	.200*	.938	10	.528
	MMA Rebase-H	.189	10	.200*	.916	10	.321
	MFMA Rebase-H	.216	10	.200*	.856	10	.068
	Ad Rebase-H	.136	10	.200*	.976	10	.939
	MMA Ad Rebase-H	.178	10	.200*	.941	10	.565
	MFMA Ad Rebase-H	.254	10	.067	.893	10	.185

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 11. Descriptive Statistics of two-way ANOVA analysis (For Tokuyama® rebase II Fast = without hardener).

Descriptive Statistics

Dependent Variable: Maxstress3x3

Product	SurfaceTx	Mean	Std. Deviation	N
Unifast	Control	79.5640	2.35170	10
	MMA	88.9410	3.72188	10
	MF-MA	97.5260	2.35935	10
	Total	88.6770	7.96275	30
Kooliner	Control	72.2840	2.47284	10
	MMA	76.4160	3.18002	10
	MF-MA	81.0930	2.16877	10
	Total	76.5977	4.46004	30
Rebase-H	Control	60.1800	2.52232	10
	MMA	64.9500	1.98015	10
	MF-MA	72.6430	1.41979	10
	Total	65.9243	5.57569	30
Total	Control	70.6760	8.46809	30
	MMA	76.7690	10.39012	30
	MF-MA	83.7540	10.68774	30
	Total	77.0663	11.16391	90

CHULALONGKORN UNIVERSITY

Table 12. The Levene statistical analysis of hard reline materials and the surface treatments (For Tokuyama® rebase II Fast = without hardener).

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Maxstress3x3

F	df1	df2	Sig.
1.629	8	81	.129

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Product3x3 + SurfaceTx3x3 + Product3x3 * SurfaceTx3x3

Table 13. The Levene statistical analysis of Unifast Trad®.

Test of Homogeneity of Variances

Maxstress

Levene Statistic	df1	df2	Sig.
1.633	2	27	.214

Table 14. One-way ANOVA analysis and Post Hoc Tests of Unifast Trad®.

ANOVA

Maxstress_column

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1614.213	2	807.106	97.049	.000
Within Groups	224.545	27	8.316		
Total	1838.757	29			

Multiple Comparisons

Dependent Variable: Maxstress_column

	(I) SurfaceTx_column	(J) SurfaceTx_column	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Tukey HSD	No Tx	MMA	-9.37700*	1.28969	.000	-12.5747	-6.1793
		MFMA	-17.96200*	1.28969	.000	-21.1597	-14.7643
	MMA	No Tx	9.37700*	1.28969	.000	6.1793	12.5747
		MFMA	-8.58500*	1.28969	.000	-11.7827	-5.3873
	MFMA	No Tx	17.96200*	1.28969	.000	14.7643	21.1597
		MMA	8.58500*	1.28969	.000	5.3873	11.7827
	No Tx	MMA	-9.37700*	1.39222	.000	-12.9883	-5.7657

Games-Howell		MFMA	-17.96200*	1.05342	.000	-20.6505	-15.2735
	MMA	No Tx	9.37700*	1.39222	.000	5.7657	12.9883
		MFMA	-8.58500*	1.39352	.000	-12.1989	-4.9711
	MFMA	No Tx	17.96200*	1.05342	.000	15.2735	20.6505
		MMA	8.58500*	1.39352	.000	4.9711	12.1989

*. The mean difference is significant at the 0.05 level.

Maxstress_column

			Subset for alpha = 0.05		
	SurfaceTx_column	N	1	2	3
Tukey HSD[a]	No Tx	10	79.5640		
	MMA	10		88.9410	
	MFMA	10			97.5260
	Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

Table 15. The Levene statistical analysis of Kooliner®.

Test of Homogeneity of Variances

Maxstress

Levene Statistic	df1	df2	Sig.
1.213	2	27	.313

Table 16. One-way ANOVA analysis and Post Hoc Tests of Kooliner®.

ANOVA

Maxstress

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	388.487	2	194.244	27.841	.000
Within Groups	188.379	27	6.977		
Total	576.866	29			

Multiple Comparisons

Dependent Variable: Maxstress_column

	(I) SurfaceTx_column	(J) SurfaceTx_column	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	No Tx	MMA	-4.13200*	1.18127	.005	-7.0609	-1.2031
		MFMA	-8.80900*	1.18127	.000	-11.7379	-5.8801
	MMA	No Tx	4.13200*	1.18127	.005	1.2031	7.0609
		MFMA	-4.67700*	1.18127	.001	-7.6059	-1.7481
	MFMA	No Tx	8.80900*	1.18127	.000	5.8801	11.7379
		MMA	4.67700*	1.18127	.001	1.7481	7.6059
Games-Howell	No Tx	MMA	-4.13200*	1.27387	.013	-7.4005	-.8635
		MFMA	-8.80900*	1.04012	.000	-11.4675	-6.1505
	MMA	No Tx	4.13200*	1.27387	.013	.8635	7.4005
		MFMA	-4.67700*	1.21721	.004	-7.8201	-1.5339
	MFMA	No Tx	8.80900*	1.04012	.000	6.1505	11.4675
		MMA	4.67700*	1.21721	.004	1.5339	7.8201

*. The mean difference is significant at the 0.05 level.

Maxstress_column

	SurfaceTx_column	N	Subset for alpha = 0.05		
			1	2	3
Tukey HSD[a]	No Tx	10	72.2840		
	MMA	10		76.4160	
	MFMA	10			81.0930
	Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

Table 17. The Levene statistical analysis of Tokuyama® Rebase II with hardener.

Test of Homogeneity of Variances

Maxstress_column

Levene Statistic	df1	df2	Sig.
.476	5	54	.793

Table 18. One-way ANOVA analysis and Post Hoc Tests of Tokuyama® Rebase II with hardener.

ANOVA

Maxstress_column

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1742.981	5	348.596	62.603	.000
Within Groups	300.690	54	5.568		
Total	2043.671	59			

Multiple Comparisons

Dependent Variable: Maxstress_column

	(I) SurfaceTx_column	(J) SurfaceTx_column	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Tukey HSD	No Tx	MMA	-4.54300*	1.05530	.001	-7.6609	-1.4251
		MFMA	-11.91300*	1.05530	.000	-15.0309	-8.7951
		Ad	-6.83400*	1.05530	.000	-9.9519	-3.7161
		MMA Ad	-11.93100*	1.05530	.000	-15.0489	-8.8131
		MFMA Ad	-16.26100*	1.05530	.000	-19.3789	-13.1431
	MMA	No Tx	4.54300*	1.05530	.001	1.4251	7.6609
		MFMA	-7.37000*	1.05530	.000	-10.4879	-4.2521
		Ad	-2.29100	1.05530	.268	-5.4089	.8269
		MMA Ad	-7.38800*	1.05530	.000	-10.5059	-4.2701
		MFMA Ad	-11.71800*	1.05530	.000	-14.8359	-8.6001
	MFMA	No Tx	11.91300*	1.05530	.000	8.7951	15.0309

		MMA	7.37000*	1.05530	.000	4.2521	10.4879
		Ad	5.07900*	1.05530	.000	1.9611	8.1969
		MMA Ad	-.01800	1.05530	1.000	-3.1359	3.0999
		MFMA Ad	-4.34800*	1.05530	.002	-7.4659	-1.2301
	Ad	No Tx	6.83400*	1.05530	.000	3.7161	9.9519
		MMA	2.29100	1.05530	.268	-.8269	5.4089
		MFMA	-5.07900*	1.05530	.000	-8.1969	-1.9611
		MMA Ad	-5.09700*	1.05530	.000	-8.2149	-1.9791
		MFMA Ad	-9.42700*	1.05530	.000	-12.5449	-6.3091
	MMA Ad	No Tx	11.93100*	1.05530	.000	8.8131	15.0489
		MMA	7.38800*	1.05530	.000	4.2701	10.5059
		MFMA	.01800	1.05530	1.000	-3.0999	3.1359
		Ad	5.09700*	1.05530	.000	1.9791	8.2149
		MFMA Ad	-4.33000*	1.05530	.002	-7.4479	-1.2121
	MFMA Ad	No Tx	16.26100*	1.05530	.000	13.1431	19.3789
		MMA	11.71800*	1.05530	.000	8.6001	14.8359
		MFMA	4.34800*	1.05530	.002	1.2301	7.4659
		Ad	9.42700*	1.05530	.000	6.3091	12.5449
		MMA Ad	4.33000*	1.05530	.002	1.2121	7.4479
Games-Howell	No Tx	MMA	-4.54300*	1.04500	.005	-7.8676	-1.2184
		MFMA	-11.91300*	1.10145	.000	-15.4135	-8.4125
		Ad	-6.83400*	.91424	.000	-9.8007	-3.8673
		MMA Ad	-11.93100*	1.08180	.000	-15.3692	-8.4928
		MFMA Ad	-16.26100*	1.19510	.000	-20.0698	-12.4522
	MMA	No Tx	4.54300*	1.04500	.005	1.2184	7.8676
		MFMA	-7.37000*	1.05162	.000	-10.7165	-4.0235
		Ad	-2.29100	.85355	.133	-5.0408	.4588
		MMA Ad	-7.38800*	1.03102	.000	-10.6666	-4.1094
		MFMA Ad	-11.71800*	1.14934	.000	-15.3968	-8.0392
	MFMA	No Tx	11.91300*	1.10145	.000	8.4125	15.4135
		MMA	7.37000*	1.05162	.000	4.0235	10.7165
		Ad	5.07900*	.92181	.001	2.0850	8.0730

		MMA Ad	-.01800	1.08820	1.000	-3.4768	3.4408
		MFMA Ad	-4.34800*	1.20090	.021	-8.1739	-.5221
	Ad	No Tx	6.83400*	.91424	.000	3.8673	9.8007
		MMA	2.29100	.85355	.133	-.4588	5.0408
		MFMA	-5.07900*	.92181	.001	-8.0730	-2.0850
		MMA Ad	-5.09700*	.89823	.000	-8.0062	-2.1878
		MFMA Ad	-9.42700*	1.03189	.000	-12.8205	-6.0335
	MMA Ad	No Tx	11.93100*	1.08180	.000	8.4928	15.3692
		MMA	7.38800*	1.03102	.000	4.1094	10.6666
		MFMA	.01800	1.08820	1.000	-3.4408	3.4768
		Ad	5.09700*	.89823	.000	2.1878	8.0062
		MFMA Ad	-4.33000*	1.18290	.019	-8.1034	-.5566
	MFMA Ad	No Tx	16.26100*	1.19510	.000	12.4522	20.0698
		MMA	11.71800*	1.14934	.000	8.0392	15.3968
		MFMA	4.34800*	1.20090	.021	.5221	8.1739
		Ad	9.42700*	1.03189	.000	6.0335	12.8205
		MMA Ad	4.33000*	1.18290	.019	.5566	8.1034

*. The mean difference is significant at the 0.05 level.

จุฬาลงกรณ์มหาวิทยาลัย

Maxstress_column

	SurfaceTx_column	N	Subset for alpha = 0.05			
			1	2	3	4
Tukey HSD[a]	No Tx	10	60.0590			
	MMA	10		64.6020		
	Ad	10		66.8930		
	MFMA	10			71.9720	
	MMA Ad	10			71.9900	
	MFMA Ad	10				76.3200
	Sig.		1.000	.268	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

Table 19. The Levene statistical analysis of Tokuyama® Rebase II without hardener.

Test of Homogeneity of Variances

Maxstress_column

Levene Statistic	df1	df2	Sig.
.757	5	54	.585

Table 20. One-way ANOVA analysis and Post Hoc Tests of Tokuyama® Rebase II without hardener.

ANOVA

Maxstress_column

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1950.496	5	390.099	69.797	.000
Within Groups	301.808	54	5.589		
Total	2252.304	59			

Multiple Comparisons

Dependent Variable: Maxstress_column

	(I) SurfaceTx_column	(J) SurfaceTx_column	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Tukey HSD	No Tx	MMA	-4.77000*	1.05726	.000	-7.8937	-1.6463
		MFMA	-12.46300*	1.05726	.000	-15.5867	-9.3393
		Ad	-5.52100*	1.05726	.000	-8.6447	-2.3973
		MMA Ad	-11.34200*	1.05726	.000	-14.4657	-8.2183
		MFMA Ad	-17.23200*	1.05726	.000	-20.3557	-14.1083
	MMA	No Tx	4.77000*	1.05726	.000	1.6463	7.8937
		MFMA	-7.69300*	1.05726	.000	-10.8167	-4.5693
		Ad	-.75100	1.05726	.980	-3.8747	2.3727
		MMA Ad	-6.57200*	1.05726	.000	-9.6957	-3.4483
		MFMA Ad	-12.46200*	1.05726	.000	-15.5857	-9.3383

	MFMA	No Tx	12.46300*	1.05726	.000	9.3393	15.5867
		MMA	7.69300*	1.05726	.000	4.5693	10.8167
		Ad	6.94200*	1.05726	.000	3.8183	10.0657
		MMA Ad	1.12100	1.05726	.895	-2.0027	4.2447
		MFMA Ad	-4.76900*	1.05726	.000	-7.8927	-1.6453
	Ad	No Tx	5.52100*	1.05726	.000	2.3973	8.6447
		MMA	.75100	1.05726	.980	-2.3727	3.8747
		MFMA	-6.94200*	1.05726	.000	-10.0657	-3.8183
		MMA Ad	-5.82100*	1.05726	.000	-8.9447	-2.6973
		MFMA Ad	-11.71100*	1.05726	.000	-14.8347	-8.5873
	MMA Ad	No Tx	11.34200*	1.05726	.000	8.2183	14.4657
		MMA	6.57200*	1.05726	.000	3.4483	9.6957
		MFMA	-1.12100	1.05726	.895	-4.2447	2.0027
		Ad	5.82100*	1.05726	.000	2.6973	8.9447
		MFMA Ad	-5.89000*	1.05726	.000	-9.0137	-2.7663
	MFMA Ad	No Tx	17.23200*	1.05726	.000	14.1083	20.3557
		MMA	12.46200*	1.05726	.000	9.3383	15.5857
		MFMA	4.76900*	1.05726	.000	1.6453	7.8927
		Ad	11.71100*	1.05726	.000	8.5873	14.8347
		MMA Ad	5.89000*	1.05726	.000	2.7663	9.0137
Games-Howell	No Tx	MMA	-4.77000*	1.01406	.002	-8.0128	-1.5272
		MFMA	-12.46300*	.91531	.000	-15.4596	-9.4664
		Ad	-5.52100*	1.15129	.002	-9.1805	-1.8615
		MMA Ad	-11.34200*	1.11764	.000	-14.8940	-7.7900
		MFMA Ad	-17.23200*	1.20730	.000	-21.0757	-13.3883
	MMA	No Tx	4.77000*	1.01406	.002	1.5272	8.0128
		MFMA	-7.69300*	.77051	.000	-10.1697	-5.2163
		Ad	-.75100	1.03989	.976	-4.0834	2.5814
		MMA Ad	-6.57200*	1.00250	.000	-9.7750	-3.3690
		MFMA Ad	-12.46200*	1.10158	.000	-16.0115	-8.9125
	MFMA	No Tx	12.46300*	.91531	.000	9.4664	15.4596
		MMA	7.69300*	.77051	.000	5.2163	10.1697

		Ad	6.94200*	.94384	.000	3.8414	10.0426
		MMA Ad	1.12100	.90249	.810	-1.8291	4.0711
		MFMA Ad	-4.76900*	1.01141	.004	-8.1164	-1.4216
	Ad	No Tx	5.52100*	1.15129	.002	1.8615	9.1805
		MMA	.75100	1.03989	.976	-2.5814	4.0834
		MFMA	-6.94200*	.94384	.000	-10.0426	-3.8414
		MMA Ad	-5.82100*	1.14112	.001	-9.4489	-2.1931
		MFMA Ad	-11.71100*	1.22908	.000	-15.6203	-7.8017
	MMA Ad	No Tx	11.34200*	1.11764	.000	7.7900	14.8940
		MMA	6.57200*	1.00250	.000	3.3690	9.7750
		MFMA	-1.12100	.90249	.810	-4.0711	1.8291
		Ad	5.82100*	1.14112	.001	2.1931	9.4489
		MFMA Ad	-5.89000*	1.19761	.001	-9.7049	-2.0751
	MFMA Ad	No Tx	17.23200*	1.20730	.000	13.3883	21.0757
		MMA	12.46200*	1.10158	.000	8.9125	16.0115
		MFMA	4.76900*	1.01141	.004	1.4216	8.1164
		Ad	11.71100*	1.22908	.000	7.8017	15.6203
		MMA Ad	5.89000*	1.19761	.001	2.0751	9.7049

*. The mean difference is significant at the 0.05 level.

จุฬาลงกรณ์มหาวิทยาลัย

Maxstress_column

	SurfaceTx_column	N	Subset for alpha = 0.05			
			1	2	3	4
Tukey HSD[a]	No Tx	10	60.1800			
	MMA	10		64.9500		
	Ad	10		65.7010		
	MMA Ad	10			71.5220	
	MFMA	10			72.6430	
	MFMA Ad	10				77.4120
	Sig.		1.000	.980	.895	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

Table 21. The Levene statistical analysis of control group.

Test of Homogeneity of Variances

Maxstress_column

Levene Statistic	df1	df2	Sig.
.128	3	36	.943

Table 22. One-way ANOVA analysis and Post Hoc Tests of control group.

ANOVA

Maxstress_column

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2762.887	3	920.962	153.468	.000
Within Groups	216.036	36	6.001		
Total	2978.923	39			

Multiple Comparisons

Dependent Variable: Maxstress_column

	(I) Product_column	(J) Product_column	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Tukey HSD	Unifast	Kooliner	7.28000*	1.09554	.000	4.3295	10.2305
		Rebase+H	19.50500*	1.09554	.000	16.5545	22.4555
		Rebase-H	19.38400*	1.09554	.000	16.4335	22.3345
	Kooliner	Unifast	-7.28000*	1.09554	.000	-10.2305	-4.3295
		Rebase+H	12.22500*	1.09554	.000	9.2745	15.1755
		Rebase-H	12.10400*	1.09554	.000	9.1535	15.0545
	Rebase+H	Unifast	-19.50500*	1.09554	.000	-22.4555	-16.5545
		Kooliner	-12.22500*	1.09554	.000	-15.1755	-9.2745
		Rebase-H	-.12100	1.09554	1.000	-3.0715	2.8295
	Rebase-H	Unifast	-19.38400*	1.09554	.000	-22.3345	-16.4335

		Kooliner	-12.10400*	1.09554	.000	-15.0545	-9.1535
		Rebase+H	.12100	1.09554	1.000	-2.8295	3.0715
Games-Howell	Unifast	Kooliner	7.28000*	1.07914	.000	4.2293	10.3307
		Rebase+H	19.50500*	1.07364	.000	16.4701	22.5399
		Rebase-H	19.38400*	1.09053	.000	16.3004	22.4676
	Kooliner	Unifast	-7.28000*	1.07914	.000	-10.3307	-4.2293
		Rebase+H	12.22500*	1.10052	.000	9.1146	15.3354
		Rebase-H	12.10400*	1.11701	.000	8.9469	15.2611
	Rebase+H	Unifast	-19.50500*	1.07364	.000	-22.5399	-16.4701
		Kooliner	-12.22500*	1.10052	.000	-15.3354	-9.1146
		Rebase-H	-.12100	1.11169	1.000	-3.2632	3.0212
	Rebase-H	Unifast	-19.38400*	1.09053	.000	-22.4676	-16.3004
		Kooliner	-12.10400*	1.11701	.000	-15.2611	-8.9469
		Rebase+H	.12100	1.11169	1.000	-3.0212	3.2632

*. The mean difference is significant at the 0.05 level.

Maxstress_column

	Product_column	N	Subset for alpha = 0.05		
			1	2	3
Tukey HSD[a]	Rebase+H	10	60.0590		
	Rebase-H	10	60.1800		
	Kooliner	10		72.2840	
	Unifast	10			79.5640
	Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

Table 23. The Levene statistical analysis of MMA group.

Test of Homogeneity of Variances

Maxstress_column

Levene Statistic	df1	df2	Sig.
2.260	3	36	.098

Table 24. One-way ANOVA analysis and Post Hoc Tests of MMA group.

ANOVA

Maxstress_column

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3989.979	3	1329.993	162.147	.000
Within Groups	295.286	36	8.202		
Total	4285.265	39			

Multiple Comparisons

Dependent Variable: Maxstress_column

	(I) Product_column	(J) Product_column	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Tukey HSD	Unifast	Kooliner	12.52500*	1.28081	.000	9.0755	15.9745
		Rebase+H	24.33900*	1.28081	.000	20.8895	27.7885
		Rebase-H	23.99100*	1.28081	.000	20.5415	27.4405
	Kooliner	Unifast	-12.52500*	1.28081	.000	-15.9745	-9.0755
		Rebase+H	11.81400*	1.28081	.000	8.3645	15.2635
		Rebase-H	11.46600*	1.28081	.000	8.0165	14.9155
	Rebase+H	Unifast	-24.33900*	1.28081	.000	-27.7885	-20.8895
		Kooliner	-11.81400*	1.28081	.000	-15.2635	-8.3645
		Rebase-H	-.34800	1.28081	.993	-3.7975	3.1015

	Rebase-H	Unifast	-23.99100*	1.28081	.000	-27.4405	-20.5415
		Kooliner	-11.46600*	1.28081	.000	-14.9155	-8.0165
		Rebase+H	.34800	1.28081	.993	-3.1015	3.7975
Games-Howell	Unifast	Kooliner	12.52500*	1.54806	.000	8.1393	16.9107
		Rebase+H	24.33900*	1.37026	.000	20.3796	28.2984
		Rebase-H	23.99100*	1.33317	.000	20.1059	27.8761
	Kooliner	Unifast	-12.52500*	1.54806	.000	-16.9107	-8.1393
		Rebase+H	11.81400*	1.22622	.000	8.3078	15.3202
		Rebase-H	11.46600*	1.18463	.000	8.0535	14.8785
	Rebase+H	Unifast	-24.33900*	1.37026	.000	-28.2984	-20.3796
		Kooliner	-11.81400*	1.22622	.000	-15.3202	-8.3078
		Rebase-H	-.34800	.94046	.982	-3.0093	2.3133
	Rebase-H	Unifast	-23.99100*	1.33317	.000	-27.8761	-20.1059
		Kooliner	-11.46600*	1.18463	.000	-14.8785	-8.0535
		Rebase+H	.34800	.94046	.982	-2.3133	3.0093

*. The mean difference is significant at the 0.05 level.

Maxstress_column

	Product_column	N	Subset for alpha = 0.05		
			1	2	3
Tukey HSD[a]	Rebase+H	10	64.6020		
	Rebase-H	10	64.9500		
	Kooliner	10		76.4160	
	Unifast	10			88.9410
	Sig.		.993	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

Table 25. The Levene statistical analysis of MF-MA group.

Test of Homogeneity of Variances

Maxstress_column

Levene Statistic	df1	df2	Sig.
1.095	3	36	.364

Table 26. One-way ANOVA analysis and Post Hoc Tests of MF-MA group.

ANOVA

Maxstress_column

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4243.149	3	1414.383	307.117	.000
Within Groups	165.793	36	4.605		
Total	4408.941	39			

Multiple Comparisons

Dependent Variable: Maxstress_column

	(I) Product_column	(J) Product_column	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Tukey HSD	Unifast	Kooliner	16.43300*	.95972	.000	13.8482	19.0178
		Rebase+H	25.55400*	.95972	.000	22.9692	28.1388
		Rebase-H	24.88300*	.95972	.000	22.2982	27.4678
	Kooliner	Unifast	-16.43300*	.95972	.000	-19.0178	-13.8482
		Rebase+H	9.12100*	.95972	.000	6.5362	11.7058
		Rebase-H	8.45000*	.95972	.000	5.8652	11.0348
	Rebase+H	Unifast	-25.55400*	.95972	.000	-28.1388	-22.9692
		Kooliner	-9.12100*	.95972	.000	-11.7058	-6.5362
		Rebase-H	-.67100	.95972	.897	-3.2558	1.9138

	Rebase-H	Unifast	-24.88300*	.95972	.000	-27.4678	-22.2982
		Kooliner	-8.45000*	.95972	.000	-11.0348	-5.8652
		Rebase+H	.67100	.95972	.897	-1.9138	3.2558
Games-Howell	Unifast	Kooliner	16.43300*	1.01341	.000	13.5668	19.2992
		Rebase+H	25.55400*	1.08176	.000	22.4959	28.6121
		Rebase-H	24.88300*	.87077	.000	22.3686	27.3974
	Kooliner	Unifast	-16.43300*	1.01341	.000	-19.2992	-13.5668
		Rebase+H	9.12100*	1.04111	.000	6.1735	12.0685
		Rebase-H	8.45000*	.81972	.000	6.0967	10.8033
	Rebase+H	Unifast	-25.55400*	1.08176	.000	-28.6121	-22.4959
		Kooliner	-9.12100*	1.04111	.000	-12.0685	-6.1735
		Rebase-H	-.67100	.90285	.878	-3.2874	1.9454
	Rebase-H	Unifast	-24.88300*	.87077	.000	-27.3974	-22.3686
		Kooliner	-8.45000*	.81972	.000	-10.8033	-6.0967
		Rebase+H	.67100	.90285	.878	-1.9454	3.2874

*. The mean difference is significant at the 0.05 level.

Maxstress_column

	Product_column	N	Subset for alpha = 0.05		
			1	2	3
Tukey HSD[a]	Rebase+H	10	71.9720		
	Rebase-H	10	72.6430		
	Kooliner	10		81.0930	
	Unifast	10			97.5260
	Sig.		.897	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

Table 27. The Levene statistical analysis of Adhesive group.

Test of Homogeneity of Variances

Maxstress_column

Levene Statistic	df1	df2	Sig.
1.342	1	18	.262

Table 28. One-way ANOVA analysis of Adhesive group.

ANOVA

Maxstress_column

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7.104	1	7.104	1.535	.231
Within Groups	83.289	18	4.627		
Total	90.394	19			

Table 29. The Levene statistical analysis of MMA+Adhesive group.

Test of Homogeneity of Variances

Maxstress

Levene Statistic	df1	df2	Sig.
.000	1	18	.985

CHULALONGKORN UNIVERSITY

Table 30. One-way ANOVA analysis of MMA+Adhesive group.

ANOVA

Maxstress

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.095	1	1.095	.185	.672
Within Groups	106.518	18	5.918		
Total	107.613	19			

Table 31. The Levene statistical analysis of MF-MA+Adhesive group.

Test of Homogeneity of Variances

Maxstress

Levene Statistic	df1	df2	Sig.
.005	1	18	.945

Table 32. One-way ANOVA analysis of MF-MA+Adhesive group.

ANOVA

Maxstress

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5.962	1	5.962	.723	.406
Within Groups	148.499	18	8.250		
Total	154.462	19			

Table 33. Descriptive Statistics of three-way ANOVA analysis of Tokuyama® Rebase II Fast.

Descriptive Statistics

Dependent Variable: RB_Maxstress

Product_RB	RB_SurfaceTx	RB_Adhesive	Mean	Std. Deviation	N
Rebase - Hardener	Control	without Adhesive	60.1800	2.52232	10
		with Adhesive	65.7010	2.62538	10
		Total	62.9405	3.78153	20
	MMA	without Adhesive	64.9500	1.98015	10
		with Adhesive	71.5220	2.47568	10
		Total	68.2360	4.01580	20
	MF-MA	without Adhesive	72.6430	1.41979	10
		with Adhesive	77.4120	2.86596	10
		Total	75.0275	3.29100	20

	Total	without Adhesive	65.9243	5.57569	30
		with Adhesive	71.5450	5.49879	30
		Total	68.7347	6.17856	60
Rebase + Hardener	Control	without Adhesive	60.0590	2.44878	10
		with Adhesive	66.8930	1.53680	10
		Total	63.4760	4.03108	20
	MMA	without Adhesive	64.6020	2.21893	10
		with Adhesive	71.9900	2.38879	10
		Total	68.2960	4.40444	20
	MF-MA	without Adhesive	71.9720	2.47700	10
		with Adhesive	76.3200	2.87858	10
		Total	74.1460	3.43604	20
	Total	without Adhesive	65.5443	5.49739	30
		with Adhesive	71.7343	4.52011	30
		Total	68.6393	5.88545	60
Total	Control	without Adhesive	60.1195	2.42032	20
		with Adhesive	66.2970	2.18119	20
		Total	63.2083	3.86738	40
	MMA	without Adhesive	64.7760	2.05461	20
		with Adhesive	71.7560	2.37988	20
		Total	68.2660	4.16033	40
	MF-MA	without Adhesive	72.3075	1.99490	20
		with Adhesive	76.8660	2.85124	20
		Total	74.5867	3.35075	40

	Total	without Adhesive	65.7343	5.49290	60
		with Adhesive	71.6397	4.99137	60
		Total	68.6870	6.00857	120

Table 34. The Levene statistical analysis of Tokuyama® Rebase II Fast (Hardener, Manfacuture Adhesive, Surface treatment).

Levene's Test of Equality of Error Variances[a]

Dependent Variable: RB_Maxstress

F	df1	df2	Sig.
.578	11	108	.843

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Product_RB + RB_SurfaceTx + RB_Adhesive + Product_RB * RB_SurfaceTx + Product_RB * RB_Adhesive + RB_SurfaceTx * RB_Adhesive + Product_RB * RB_SurfaceTx * RB_Adhesive

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

VITA

NAME	Mister Mongkol Puangpetch
DATE OF BIRTH	7 October 1982
PLACE OF BIRTH	Phimai, Nakhon Ratchasima, Thailand
INSTITUTIONS ATTENDED	Phimai Wittaya School Bachelor degree of Science (Radiological Technology), Naresuan University Doctor of Dental Surgery (D.D.S), Faculty of Dentistry, Thammasat University Master Science in Prosthodontics, Faculty of Dentistry, Chulalongkorn University
HOME ADDRESS	Phimai, Nakhon Ratchasima, Thailand

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY