EFFECTS OF NON-MMA BASED HARD RELINE MATERIALS ON THE MECHANICAL AND ADHESION PROPERTIES OF REPAIRED DENTURE BASE

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WEERAPHAT RUNGRUEANG

A Thesis Submitted in Partial Fulfillment of the Requirements

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THE THESIS TITLED

EFFECTS OF NON-MMA BASED HARD RELINE MATERIALS ON THE MECHANICAL AND ADHESION PROPERTIES OF REPAIRED DENTURE BASE

BY

WEERAPHAT RUNGRUEANG

HAS BEEN APPROVED BY THE GRADUATE SCHOOL IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE MASTER OF SCIENCE IN CLINICAL DENTISTRY AT SRINAKHARINWIROT UNIVERSITY

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Objective: To evaluate the mechanical properties of flexural strength and tensile bond strength of repaired denture base material with three commercially non-MMA based hard reline and one MMA based auto-polymerized acrylic resin, before and after thermal cycling. Methods: A heat-polymerized acrylic resin (ProBase Hot) was fabricated using the dimensions of 64 x 10 x 3.3 mm (intact group, N=20) and 30.5 x 10 x 3.3 mm (repaired group, N=320). The two plates of the repaired group were repaired using Unifast Trad (N=40), Ufi Gel hard (N=40), Tokuyama Rebase II (N=40), and Kooliner (N=40) with the dimensions of 64 x 10 x 3.3 mm. The repaired joint was kept at a gap width of 3 mm and prepared with a 45° bevel joint in the middle. Half of the specimens in each group (intact group N=10, repaired group N=20) were exposed to 5000 thermal cycles between 5 °C and 55 °C with a 30-second dwell time. The flexural strength test (intact, Unifast Trad, Ufi Gel hard, Tokuyama Rebase II, Kooliner) and the tensile bond strength test (Unifast Trad, Ufi Gel hard, Tokuyama Rebase II, Kooliner), consisted of both non-thermal cycling (N=10) and thermal cycling (N=10) were performed on the specimens. The mode of failure was evaluated. The statistical analysis of data was conducted using two-way analysis of variance (two-way ANOVA) and Bonferroni post hoc tests ($p < .05$). Results: The flexural strength value of the intact specimens was significantly higher than all groups. Whereas flexural strength and the tensile bond strength values of Unifast Trad was significantly higher than all other repairing materials (i.e., Ufi Gel hard, Kooliner and Tokoyama Rebase II, respectively), the tensile bond strength of Ufi Gel hard was not significantly different to Unifast Trad ($p < .05$). After thermal cycling, flexural strength and tensile bond strength were reduced in almost all of the repaired specimens except Tokoyama Rebase II. The mode of failure of these tests was similar in result. This test revealed that Unifast Trad and Ufi Gel Hard were mostly cohesive failures, whereas Tokuyama Rebase II and Kooliner were mostly mixed failures. In groups of adhesive failure, Kooliner found the most. Conclusions: From the clinical point of view from our study suggest that non-MMA based material (Ufi Gel hard) can be used as an alternative for patients or dentists allergic to the MMA monomer.

Keyword : Non-MMA based hard reline material, Mechanical and adhesion, Repaired denture base

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CHAPTER 1
INTRODUCTION

Background and rationale

Fractures of acrylic resin dentures are a common problem. After using dentures for three years, the fracture rate is around 68%.[1] Many studies have found that fractures of upper dentures occur more frequently than lower dentures. The main causes of a denture fracture is occlusal force, lack of retention, material fatigue and accidental dropping.[2-4] To solve this problem, there are two options: fabricating new dentures or denture repair. Denture repair is the routine method for fractured dentures because fabricating new dentures is expensive and time-consuming.[4] After a denture repair, the dentures should be restored to their original strength and thus will prevent further fractures.[5]

Acrylic resin dentures are usually made from heat-polymerized acrylic resin, which is a kind of polymethyl methacrylate (PMMA). Previous studies have shown that many types of material are available for repairing acrylic resin dentures; for example, heat-polymerized acrylic resin, auto-polymerized acrylic resin, light-polymerized acrylic resin and microwave-polymerized acrylic resin.[4, 6] However, the most widely used material for denture repairs is auto-polymerized acrylic. The main reasons are because it is an easy method to handle, it is inexpensive and also saves time.[7] On the other hand, denture repairs using auto-polymerized acrylic resin have disadvantages such as unpleasant taste, bad odor, and heat during polymerization.[4]

One key issue of auto-polymerized acrylic resin is the residual monomer or unreacted monomer, which results from polymerization of auto-polymerized acrylic resin at a low degree of conversion. Residual monomer contains methyl methacrylate (MMA) monomer which irritates the oral soft tissue and can cause allergies in patient[8] and dental personnel.[9] Previous studies have shown that wearing medical gloves does not protect dental personnel from contact with MMA monomer because it can penetrate through them.[10-12]

More recently, dental personnel have been using a non-MMA based hard reline material for relining the acrylic resin denture by chairside reline technique instead of by relining dentures using an MMA based auto-polymerized acrylic resin. In general, the powder composition of non-MMA base hard reline materials is polyethyl methacrylate (PEMA), which has a different composition from the denture base material (PMMA). Moreover, this also contains a different liquid monomer which is higher in molecular weight than methyl mathacrylate and results in less irritation to oral soft tissue.[13] Mutluay et al.[8] that the tensile bond strength of non-MMA base hard reline materials (which do not contain an MMA monomer) have a similar tensile bond strength to an MMA based reline material.

Furthermore Seo et[14] found that the flexural strength of Ufi Gel hard C and Tokuso rebase fast were not significantly different from Lucitone 550 (heat-polymerized acrylic resin).

In the same manner, non-MMA based hard reline materials have been used to replace some parts of the acrylic resin denture. Hence, they are useful for repairing a fractured denture. Kanchanavasita et al.[15] found that the flexural strength of a repaired denture using Unifast trad was stronger than one using non-MMA based hard reline materials. However, this study did not investigate Ufi Gel hard nor did it include a thermal cycling condition.

The strength of relined and repaired specimens depends on the volume of material, the strength of the materials, and bonding properties to each of the other materials.[16] Several studies have used the flexural strength test to evaluate the repaired material. Whereas there is little knowledge of tensile bond strength, Mutluay et al.[8] suggested that it is a simple method which uses tensile force to join materials. Stipho[5] pointed out that the strength of repaired dentures depends on bonding between the repaired material and the denture base material that A weak bond results in bacterial accumulations, increasing stains and separation of the repaired and denture base material.[17]

Generally, acrylic dentures will face thermal stresses as a result of hot and cold temperature variations caused by food consumption. These temperature variations affect the physical properties of this type of denture. One previous study[18] describing thermal cycling was able to simulate the oral conditions of food consumption. In this study, the thermal cycling process was performed between 5 °C and 55 °C for 5,000 cycles with a dwell time of 30 seconds, which represented acrylic denture use for 6 months. Moreover, a little knowledge on the effect of themal cycling on flexural strength and bond strength[13] between hard reline and denture base materials.

The objective of the current study is to evaluate the effects of repaired denture base material with respect to both flexural and tensile bond strength using different non-MMA based hard reline materials and MMA based auto-polymerized acrylic resin.

Purpose of this study

To evaluate the mechanical properties of both flexural and tensile bond strength of repaired denture base material using three commercial non-MMA based hard reline materials and one MMA based auto-polymerized acrylic resin.

Significance of the research

Non-MMA based hard reline materials have been used to improve the fit of dentures by resurfacing the intaglio while maintaining the original mechanical properties of the denture. The

advantage of this material is that it is free of methyl methacrylate monomer which can cause allergic contact dermatitis. This material may be a viable alternative for denture repair in patients or dental personnel who are allergic to MMA monomer. Although non-MMA based hard reline materials have been used for many years, some materials are still problematic with respect to strength and adhesive properties. A few studies have tested the mechanical properties of a repaired acrylic denture base with non-MMA based hard reline materials.

Limitation of this study

This study is based on laboratory experimental research.

Definition of terms

Non-MMA based hard reline material

Hard reline materials not containing methyl methacrylate monomer.

Flexural strength

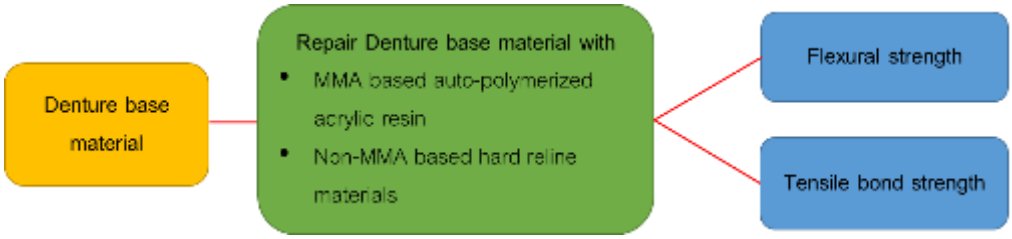
A measurement of the capacity of material resistance to deformation or fracturing of the bulk of the material under a flexural load.[19, 20]

Tensile bond strength

A measurement of the capacity of material to withstand a tensile force which is subjected to the adhesive surface between two materials[8, 20]

Conceptual of framework

Repairing denture base material has resulted in mechanical properties of denture base material. The strength of relined and repaired specimens depend on the volume of material, the strength of material, and the bonding properties with each of the other materials. The non-MMA based hard reline material has a different composition from denture base material, which maybe affects the strength of denture base material differently to repairing with MMA based auto-polymerized acrylic resin.



Variable for this study

In an experiment, the independent variable is repair material which repaired the denture base material. The dependent variables are flexural strength value and tensile bond strength value of repaired denture base materials.

Research Hypotheses

Flexural strength

H_0: There will be no significant differences in flexural strength between acrylic resin denture base repaired with non-MMA hard reline materials and MMA based auto-polymerized acrylic resin.

H_1: There will be significant differences in flexural strength between acrylic resin denture base repaired with non-MMA hard reline materials and MMA based auto-polymerized acrylic resin.

Tensile bond strength

H_0: There will be no significant differences in tensile bond strength between acrylic resin denture base repaired with non-MMA hard reline materials and MMA based auto-polymerized acrylic resin.

H_1: There will be significant differences in tensile bond strength between acrylic resin denture base repaired with non-MMA hard reline materials and MMA based auto-polymerized acrylic resin.

CHAPTER 2
REVIEW LITERATURE

1. Fracture of acrylic resin denture

Fractures of acrylic dentures are a common problem during their period of function.[2] Tomita et al.[1] examined clinical surveys of denture fracture cases from 1984 and 2009 found that they are the most common cause of denture repair. It is also worth noting that denture base fracture remained even in cases where the denture base material was reinforced.[1] Takamiya et al.[3] investigated the prevalence of use and complete denture fractures in patients who were treated in Aracatuba and Araraquara schools. They reported that the one reason that patients did not wear complete dentures after an insertion visit was denture fracture, most commonly occuring within 6 months to 1 year.[3] Another study found that approximately 68% of denture fractures occurred within 3 years after insertion.[1] Numerous studies report fractures of maxillary dentures occur more often than mandibular dentures. General causes of denture fracture are occlusal force, lack of retention, material fatigue, improper denture design and accidentally falling out.[2-4]

2. Acrylic denture base materials

Resin acrylic is a polymeric material that is widely used to fabricate an acrylic resin denture base. Denture base polymer was classified following the International Organization for Standardization (ISO) 20795-1 2013[21] (see Table 1 below).

Table 1 Classification of denture base polymers.[21, 22]

Type	Class
1: Heat-polymerizable material	1: Powder and liquid
	2: Plastic cake
2: Auto-polymerizable material	1: Powder and liquid
	2: Plastic cake
3: Thermoplastic blank or powder	-
4: Light activated materials	-
5: Microwave cured materials	-

Heat-polymerized acrylic resin and auto-polymerized acrylic resin are the most widely used materials. Heat-polymerized acrylic resin requires heat to polymerize while auto-polymerized acrylic resin can be polymerized at room temperature through chemical reaction. Heat-polymerized acrylic resin is mostly used to fabricate acrylic dentures, whereas auto-polymerized acrylic resin is used to repair or reline acrylic dentures. Generally, they have two types of material including powder and liquid (see Table 2 below).[22]

The main composition of powder is polymethyl methacrylate beads. Moreover, the powder part consists of both initiator and pigment. The initiator is a peroxide such as benzoyl peroxide. Pigment is added in the powder to improve the color of the denture base and may include salt of cadmium, iron, or organic dyes.

Regarding the liquid, the main composition is methylmethacrylate monomer (MMA) which is a colorless, low-vicosity liqiud with a boiling point of 100.3 °C. It also has a bad odor. A cross-link agent (e.g., ethylene glycol dimethacrylate) is used to improve the physical properties of the material. An inhibitor serves as the component for extending the life of the liquid such as Hydroquinone. Activators are only found in auto-polymerized acrylic resins such as *N N'*-dimethyl-p-toluidine that funtion with alongside the peroxide in powder to initiate the polymerisation.

Table 2 Composition of Heat-polymerized acrylic resin and Auto-polymerized acrylic resin.[22]

Powder	Polymer	Polymethyl methacrylate beads
	Initiator	A peroxide such as benzoyl peroxide (approximately 0.5%)
	Pigments	Salts of cadmium or iron or organic dyes
Liquid	Monomer	Methylmethacrylate
	Cross-link agent	Ethylene glycol dimethacrylate (approximately 10%)
	Inhibitor	Hydroquinone (trace)
	Activator*	*N N'*-dimethyl-p-toluidine (approximately 1%)

*only in auto-polymerized acrylic resin

Thermoplastic denture base materials are an alternative material. Not only can they be used to construct the denture base they can also be used to construct the denture clasp in patients who are concerned about esthetics. They are four types; for example, polyamide, polyester, acrylic resin, and polycarbonate.

The light-activated materials are composed of urethane dimethacrylate monomer, sub-micron paticles of silica, polymethymethacrylate beads, light sensitive initiator (camphorquinone) and the activator (amine). Light-activated materials are polymerized using a specific oven that provides the light to activate the initiator. The advantages of light-polymerized acrylic resins are reduction of chemmical irritation and thermal irritation, good color stability and good physical properties. On the other hand, the material show some limitation, for example brittle, poor adhesion to denture teeth and increase water sorption.[4]

Microwave cured materials (microwave resin) is polymerized with nonmetalic microwave flask in microwave oven which was used to active benzoyl peroxide, the intiator for polymerization process.[7] However there are difficult to use, but the advantage is great physical properties and low residual monomer.[4, 7]

3. Acrylic denture base repair materials

Acrylic dentures or part of the denture base of the removable partial denture are usually fabricated with heat-polymerized acrylic resin polymethyl methacrylate (PMMA) because of advantages with biocompatibility, esthetics, accuracy, stability in the oral environment, ease of fabication and adjustment, low cast and ease of repair. However, despite all of these advantages fractures may still occurr.[23]

Fractures of acrylic resin dentures are a common problem in prosthetic dentistry. Fabrication of new dentures is an expensive and time-consuming process which means that other methods for repairing dentures are sometimes sought; for example, with acrylic resin material, which can be used for either temporary or definitive repairs. The objective of repairing dentures is to restore the original strength of the denture and to avoid further fractures.[5] The properties of the repair material should have sufficient strength, be inexpensive, save time, and be of a similar color to the denture base color and maintain dimensional stability.[4] Previous studies have revealed that the fracture of acrylic denture can be repaired with many types of acrylic resin including heat-polymerized acrylic resin, auto-polymerized acrylic resin, light-polymerized acrylic resin and microwave-polymerized acrylic resin.[4-7] Each type of material has both advantages and disadvantages so the choice of material for repairing acrylic dentures depends on the duration of treatment, experience and opinions of dentists.[6]

Previously study[6] suggested repair denture with heat-polymerized acrylic resin or microwave-polymerized acrylic resin provide strength more than other repair materials but theses material require amount of working and special equipment for example nonmetalic microwave flask and microwave oven for microwave-polymerized acrylic resin, while metal flask and hot water boiler for heat-polymerized acrylic resin. Whatmore, repair denture base with heat-polymerized acrylic resin cause to distortion of denture. Whereas, repair the denture base with light-polymerized acrylic resin revealed mechanical properties lower than repair with auto-polymerized acrylic resin, and also require special oven for polymerization.

Auto-polymerized acrylic resin can be polymerized at room temperature by chemical reaction. The composition has shown in table 2. This material is the most widely used in repair acrylic denture[6, 7] because it is easy to use, and it saves both time and costs. However, the polymerization of auto-polymerized acrylic resin sometimes results in a low degree of conversion, resulting in residual monomer or unreactive monomer in its mechanical properties.[14] The repair strength of auto-polymerized acrylic resin varies from 40% to 90% of the original strength of denture base material.[5, 6, 24] On the other hand, Rached et al.[6] evaluated the transverse strength of a heat-polymerized acrylic resin that had been repaired with heat-polymerized acrylic resin, auto-polymerized acrylic resin, and microwave-polymerized acrylic resin, and found that the transverse strength of repairing with auto-polymerized acrylic resin was not significantly different to repairing with heat-polymerized acrylic resin. According to Stanford[25], who studied the physical properties of auto-polymerized acrylic resin for repairing dentures, found that repairing dentures with auto-polymerized acrylic resin resulted in less distortions than repairing dentures with heat polymerized acrylic resin.

4. Non-MMA hard reline materials

Relining is the method used to resurface the tissue side of a denture because the ridge usually changes and adapts through use.[26] The objective of relining dentures is to improve retention, stability, and the support of the denture.[27] Relining dentures can be processed using direct relining techniques (chairside relining technique) or indirect relining technique (laboratory technique).

Hard reline material is classified as a denture lining material that includes tissue conditioners and soft lining materials. Hard reline material is divided in two types, as shown below in Table 3.[22]

Table 3 Composition of typical hard reline material.[22]

Type 1(MMA based)	Powder	Polymer beads	Polymethyl methacrylate
		Initiator	Benzoyl peroxide
	Liquid	Monomer	Methyl methacrylate
		Plasticizer	Di-*n*-butyl phthalate
		Chemical activator	Tertiary amine
Type 2 (Non-MMA based)	Powder	Polymer beads	Polyethyl methacrylate
		Initiator	Benzoyl peroxide
	Liquid	Monomer Pigments	Butyl methacrylate or isobutyl methacrylate or some other higher methacrylate monomer
		Cross-linking agent	Di-methacrylate
		Chemical activator	Tertiary amine

The direct relining technique uses auto-polymerized acrylic resin to reline the denture directly in the patient's mouth. The patient feels heat from the setting reaction and experiences a bad odor as well as a bad taste from the methyl methacrylate monomer.[8] Unfortunately, contact with methyl methacrylate monomer can cause allergic contact dermatitis in some patients.[28] Recently, some non-MMA base hard reline material has been introduced, free of methyl methacrylate, to solve these problems; for example Tokuyama Rebase II®, Ufi Gel hard®, and Kooliner™. The composition of non-MMA base hard reline material is shown in Table 4 below.

Table 4 Composition of non-MMA base hard reline material.

Product	Composition			Manufacturer
	Polymer	Monomer	Adhesive	
1. Ufi Gel hard	PEMA	1,6-HDMA	Acetone, 2-HEMA	VOCO GmbH, Cuxhaven, Germany

Table 4 Continue

Product	Composition			Manufacturer
	Polymer	Monomer	Adhesive	
2. Tokuyama® Rebase II	PEMA	AAEMA 1,9-NDMA,	Ethyl acetate, Acetone	Tokuyama Dental Corporation, Tokyo, Japan
3. Kooliner™	PEMA	IBMA	-	GC America Inc,Illinois, USA

PEMA= Polyethyl methacrylate

1,6-HDMA= 1,6-Hexanedial dimethacrylate

2-HEMA= 2-Hydroxyethyl methacrylic

AAEMA= 2-(Acetoacetoxy) ethyl methacrylate

1,9-NDMA= 1,9-Nonanedilol dimethacrylate

IBMA= Isobutyl methacrylate

Non-MMA based hard reline materials are Polyethyl methacrylate (PEMA) which has a different composition from denture base material. Moreover, they contain monomer which has a higher molecular weight than methyl mathacrylate.[13] Previous studies have evaluated the mechanical and bonding properties that have been used as relining material. Mutluay et al.[8] suggest that non-MMA base hard reline materials that do not contain methyl methacrylate monomer have tensile bond strength similar to a methyl methacrylate based (MMA based) relining material. Furthermore, Seo et al.[14] revealed that Vickers Hardness of Ufi Gel hard C was significantly higher than the other non-MMA reline materials such as auto-polymerized acrylic resin and heat-polymerized acrylic resin. Conversely, flexural strength of Ufi Gel hard C and Tokuso rebase fast were not significantly different from Lucitone 550 (heat-polymerized acrylic resin). In contrast, Kanchanavasita et al.[15] evaluated flexural strength of repaired acrylic resin dentures with non-MMA base hard reline materials to compare with repairs made with auto-polymerized acrylic resin. They found that repairing a denture with Unifast trad produced the highest flexural strength in comparison to other materials.

5. Allergic to methyl methacrylate monomer

Acrylic resin or polymethyl methacrylate (PMMA) is used in a variety of dental applications such as denture bases, orthodontic devices, individual trays and temporary crowns. Moreover,

polymethyl methacrylate is also used for bone cement, acrylic glass, and artificial fingernails.[28] The main composition of denture base material is polymethyl methacrylate. Previous studies[9] have reported that most common allergic reactions in dental staff are allergies to latex, acrylates, and formaldehyde. The prevalence of a contact allergy to acrylate was below 1% in the population of Swedish dentists who were diagnosed with contact dermatitis.[29] Chowanadiasai et al.[30] conducted a study on occupational health problems of dentists in southern Thailand and found that the cause of contact dermatitis among 3.9% of dentists was polymethyl methacrylate In general, polymethyl methacrylate consists of polymethyl methacrylate powder and methyl methacrylate (MMA) monomer. Previous studies have found that MMA monomer is the main cause of allergies in dental personnel.[12, 28]While polymerized PMMA does not cause contact dermatitis.[12] Allergic contact dermatitis commonly show as dry, cracked finger tips and erythema. Furthermore, wearing medical gloves made form natural rubber latex or polyvinyl chloride do not protect dental personnel from coming into contact with methyl methacrylate monomer because it can penetrate through medical gloves.[10, 12] Previously study reported auto-polymerized acrylic resin which still leaks out monomer for a month after completed polymerization and lead to allergy in oral tissue.[31]

6. Thermal cycling

During the use of dentures in daily life, the acrylic denture is exposed to thermal stresses due to hot and cold temperature variations through ingesting food. These temperature variations affect the physical properties of acrylic dentures. Previous study[18] reported studies reported that water penetrated the structure of the denture base polymer resulting in separation of the polymer chain and expansion of polymer mass. Moreover, water can act as a plasticizer that affects the mechanical properties of acrylic resin, whereas heat increases space between the polymer chain of the denture base material resulting in increased water absorbtion.

Thermal cycling simulates the oral conditions. The process is performed between 5 °C and 55 °C for 5,000 cycles with a dwell time of 30 seconds, representing acrylic denture use of 6 months. However, themal cycling may decrease the physical properties of denture base material. Machado et al. revealed that both flexural and impact strength values of denture base material (Lucitone 199 and Eclipse) were reduced after thermo cycling.[18] On the other hand, some studies revealed that bond strength between an auto-polymerized acrylic resin and acrylic denture base improved after thermal cycling because the residual monomer leaked into the water and the acrylic resin continued with the polymerization process during thermal cycling.[13, 32]

7. Surface treatment

To restore the original strength of acrylic dentures after repairing them depends on the strength of the repairing material and bond strength between the repairing material and acrylic denture base material. Previous studies have reported that recurrent fractures occur at the surface of the repairing material and acrylic denture base material more frequently than fractures of the repairing material because of stress concentration at the joint's surface. Chemical surface treatment and mechanical surface treatment are used to improve bond strength.

7.1 Chemical surface treatment

Chemical surface treatment involves applying solvent to the denture base surface in preparation for bonding with the repairing material. Previous studies have incorporated various groups of chemical solvents such as methyl methacrylate monomer, methyl formate, chloroform, acetone, methyl acetate methylene chloride[7, 33] and methyl formet-methyl acetate[31]. Solvents dissolve the denture surface which softens resulting in swollen layers on the denture. Solvents will diffuse and penetrate the denture surface causing polymerization thus forming an interpenetrating polymer network (IPN) in denture base material.[8]

Previous studies have reported that swollen layers improve bond strength which depends on type of solvent and wetting time. The smaller molecular weight of a solvent is better at penetrating the denture base surface than larger molecular weights.[31] The molecular weight of chemical solvent is shown in Table 5 below.

Table 5 Molecular weight of chemical solvent[8, 31]

Solvent	Molecular weight (Da)
Aceton	58.08
methyl formate	60.05
methyl acetate	74.08
Ethyl acetate	88.11
MMA	100.12
2-HEMA	130.14
1,6 HDMA	254.33
MAOP	186
IBMA	142.20

MMA = Methyl methacrylate

1,6-HDMA= 1,6-Hexanedial dimethacrylate

2-HEMA= 2-Hydroxyethyl methacrylic

IBMA= Isobutyl methacrylate

7.2 Mechanical surface treatment

Space for repairing material is one factor that impacts the strength of a repaired denture base and the stress distribution on the repairing material. Previous studies have tested different gap widths for denture repairing; for example, 10 mm, 5mm, 3mm, 2.5mm. Beyli and von Fraunhofe[34] suggest that a gap width less than or equal to 3 mm decreases polymerization shrinkage of the repairing material and also the color difference between the repairing material and the acrylic denture base. Shanoj et al.[35] suggested suggested that a wide repair gap decreases flexural strength, a finding in line with Glad et al.[32], who showed that small gaps (1.5 mm, 1.0 mm, 0 mm) improve the flexural strength of repair specimens.

A number of previous studies have put forward different views on the appropriate shape of joint surfaces such as butt joint, 45° bevel joint, 30° bevel joint, 55° bevel joint, rounded joint and a rabbet joint.[4] Ward et al.[36] found that a rounded joint or a 45° bevel joint has a greater bond strength than a butt joint. There was no significant difference in transverse strength between a rounded joint and a 45° bevel joint with respect to the surface bonding area (rounded joint = 78 mm^2, 45° bevel joint= 72 mm^2, butt joint= 50 mm^2) (see Figure 1 below). In clinical settings, the preparation of a 45° bevel joint is easier than the preparation of a round joint. Gad M et al..[37] studied the improvement of the flexural strength of repaired denture bases with the use of nano-Zirconium dioxide in different joints (butt joint and 45° bevels). They found that 45° bevel joints increased the flexural strength.

Figure 1 Repair joint surface designs: (a) butt joint, (b) 45°bevel joint, (c) rounded joint[4]

8. Test

The strength of relined and repaired specimens depend on volume of material , the strength of the materials, and bonding properties to each other of materials.[16] The strength of repaired denture base materials has been evaluated by many method including Flexural strength test, shear bond strength test, torsional test and tensile bond strength. In this study has focused on the flexural strength and tensile bond strength.

8.1 Flexural strength

Flexural strength is a common testing method for examining the strength of a denture repair.[4, 7] It is described by the amount of force an object can take without breaking or permanently deforming. The flexural strength value is determined by three-point flexural testing (see Figure 2 below). A vertical load is applied at the midpoint of the specimen at a crosshead speed of 5 mm/min on a load testing machine until fracture of specimen.

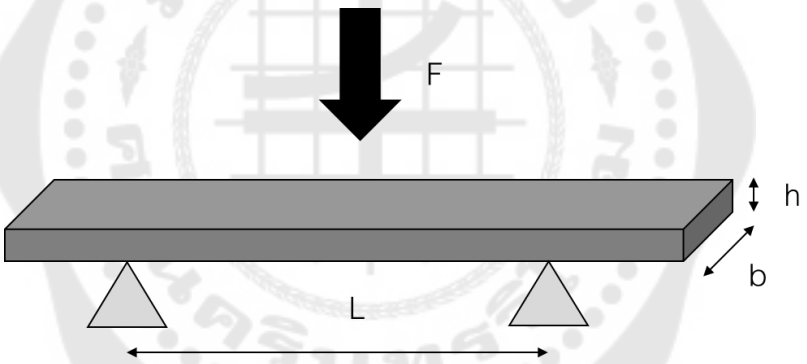


Figure 2 Three-point flexural testing.

The flexural strength (MPa) was calculated according to the following formula $FS=3FL/2bh^2$

FS = The ultimate flexural strength (MPa)

F = The maximum load (N)

L =The span distance (mm)

b = The width (mm) of the specimen

h = The height (mm) of the specimen

Specimen preparation for Flexural strength test follow to ISO (International Organization for Standardization) 20795-1:2013[21] (figure 3) with dimension of 64.0 ±0.2 × 10.0±0.2 × 3.3 ±0.2 mm. specimens are immersed in 37±1 ˚C distill water for 50±2 hours before test.

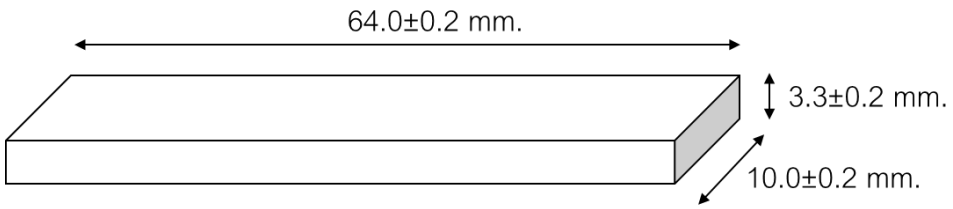


Figure 3 Specimen preparation for the flexural strength test (based on ISO 20795-1:2013).

8.2 Tensile bond strength

Tensile bond strength is the loading of tensile force on material that was bonded with other materials for investigating the bonding characteristics (see Figure 4). Stipho[5] pointed out that strength of repaired dentures depend on the bonding between the repaired material and the denture base material. A poor bond also reduces the strength of the denture base and causes fractures.[8] According to the current literature, threre is no general agreement about the testing method for evaluating the bond strength of hard reline materials.[8, 17] Mutluay et al.[8] suggested that tensile bond strength using tensile force at the junction of the materials is a simple method. It can also determine the area of fractured material. Previous research has introduced different specimen shapes for preparing tensile bond strength tests such as cylinder and dumbbell.[8, 17, 31]

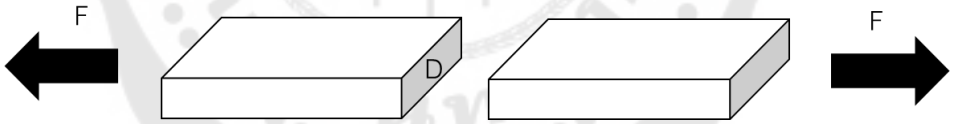


Figure 4 Tensile bond strength testing.

The tensile bond strength (MPa) was calculated according to the following formula TBS=F/D

TBS = The tensile bond strength (MPa)

F = The force (N)

D = The cross-sectional area (mm^2)

9. Mode of failure identification

Previous study[7] pointed out that fracture of repared specimens occur at junction between denture base material and repair material rather than through the center of the repair material. Simillarly, Kanchanavasita et al.[15]revealed most failure of repaired specimen were adhesive failure.

Mode of failure has been used to determine the remnants of adhesive surfaces and has been defined according to three types of mode of failure.[6, 8, 15]

1. Cohesive failure when fractures occur in repairing material or denture base material.

2. Adhesive failure when fractures occur between the interface of denture base material and repairing material.

3. Mixed failure when fractures occur in both the repairing material and interface of denture base material.

CHAPTER 3
METHODOLOGY

Materials

1. ProBase Hot® (Ivoclar Vivadent, Liechtenstein) shows in table 6 (see figure 5).

2. Unifast Trad® Pink (GC Corporation, Tokyo, Japan) shows in table 6 (see figure 6).

3. Ufi Gel hard® (VOCO GmbH, Cuxhaven,Germany) shows in table 6 (figure 6).

4. Tokuyama Rebase II® (Tokuyama Dental Corporation, Tokyo, Japan) shows in table 6 (see figure 6).

5. Kooliner™ (GC America Inc,Illinois, USA) shows in table 6 and (see figure 6).

6. Separating Fluid shows (Ivoclar Vivadent, Liechtenstein) (see figure 7).

Table 6 Materials used in this study.

Product	type	composition		Powder/liquid Ratio	adhesive	process	manufacturer
		powder	liquid				
1. ProBase Hot®	Heat-polymerized acrylic resin	PMMA	MMA	22.5g/10ml		Heat polymerized for 45 min.at 100˚c	Ivoclar Vivadent, Liechtenstein
2.Unifast Trad® Pink	Auto-polymerized acrylic resin	PMMA	MMA	1g/0.5ml		Manipulation should be finished before 2 min after mixing	GC Corporation, Tokyo, Japan
3.Ufi Gel hard®	Auto-polymerized acrylic resin	PEMA	1,6-HDMA	1.8 g/1ml	Acetone, 2-HEMA	6.5 min at room temperature follow with 2 min at 40°C warm water	VOCO GmbH, Cuxhaven, Germany

Table 6 Continue

Product	type	composition		Powder/liquid Ratio	adhesive	process	manufacturer
		powder	liquid				
4.Tokuyama Rebase II®	Auto-polymerized acrylic resin	PEMA	AAEMA 1,9-NDMA,	2.056g/1ml	Ethyl acetate, Acetone	5.5 min at environmental temperature with 3 min immersion in 40°C TOKUYAMA RESIN HARDENER II solution	Tokuyama Dental Corporation, Tokyo, Japan
5.Kooliner™	Auto-polymerized acrylic resin	PEMA	IBMA	15ml/6ml	-	10 min at environmental temperature	GC America Inc,Illinois, USA

PMMA= Polymethyl methacrylate

MMA= Methyl methacrylate

PEMA= Polyethyl methacrylate

1,6-HDMA=1,6-Hexanediol dimethacrylate

2-HEMA=2-Hydroxyethyl methacrylic

AAEMA= 2-(Acetoacetoxy) ethyl methacrylate

1,9-NDMA= 1,9-Nonanedilol dimethacrylate

IBMA= Isobutyl methacrylate

Figure 5 ProBase Hot®

Figure 6 (a)Unifast Trad® (b) Ufi Gel hard®, (c)Tokuyama Rebase II®,(d) Kooliner™

Figure 7 Separating Fluid (Ivoclar Vivadent Inc., Liechtenstein).

Method

Preparation of specimens

Intact specimen of heat-polymerized acrylic resin preparation

1. 20 specimens of heat-polymerized acrylic resin (ProBase Hot ; Ivoclar Vivadent Inc., Liechtenstein) were polymerized in stainless steel mold size 64x10x3.3 mm (figure 8). The inner surface was coated with thin separating fluid. Acrylic resin was mixed according to the manufacturer's instructions, that the powder/liquid ratio of 22.5g/10 ml was mixed and leaved in the closed mixing cup at room temperature for approximately 8 to 10 minutes for the dough stage. the dough stage material was packed into the stainless steel mold cavity and then remove excess material by trial closure method with 80 bar pressure, 2 times. (figure 9)

Figure 8 Stainless steel mold dimension 64x10x3.3 mm.

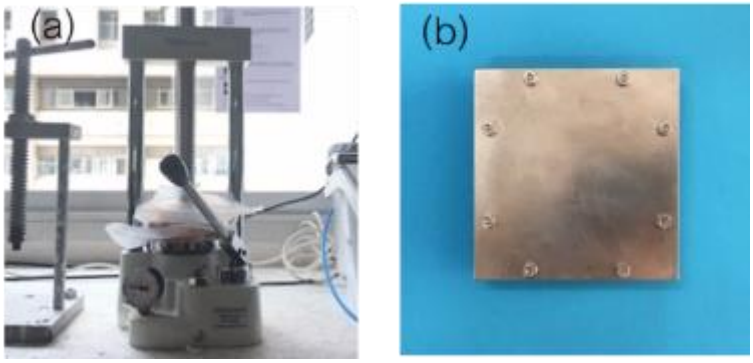


Figure 9 (a) Removal of excess material by trial closure method with 80 bar pressure and (b) the assembly was clamped with screws.

2. Specimens are processed by place closed flask in cold water. It was heated up to 100 °C for 45 minutes by hot water boiler (Labormat TH; dreve dentamid gmbh ,Unna, Germany)(figure 10). After the process, stainless steel mold was blenched cool at room temperature for 30 minutes. The specimens (figure 11) were removed from stainless steel mold and finished in dimension by automatic grinding and polishing machine with 400,600,800-grit silicon carbide paper (DCC; TOA Paint Co.,Thailand) retrospectively(figure 12). A digital caliper (Vernier Digital Series 500-180-30; Mitutoyo, Japan) was used to evaluate dimension of specimen at three location of each dimension to within 0.02 mm tolerance. The specimens (figure 13) were stored in distilled water at 37±1˚C for 50±2 hour in an incubator (incubator; Siam cement industry co., LTD.,Thailand) (figure 14) before the test.[21]

Figure 10 hot water boiler (Labormat TH; dreve dentamid gmbh ,Unna, Germany)

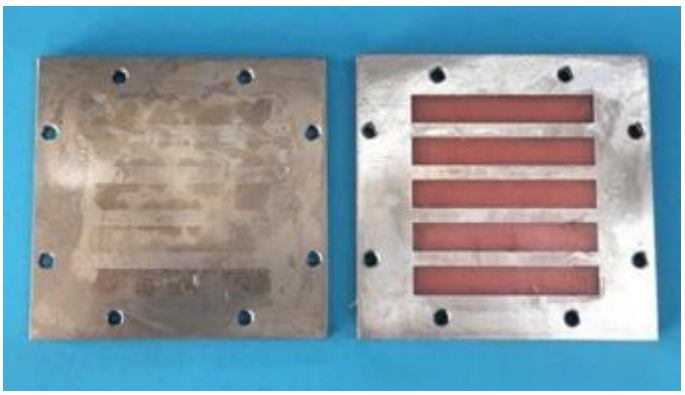


Figure 11 The specimens after the polymerized process

Figure 12 Automatic grinding and polishing machine.

Figure 13 Intact specimen of heat-polymerized acrylic resin

Figure 14 incubator (incubator; Siam cement industry co., LTD.,Thailand)

3. The 10 intact specimens of heat-polymerized acrylic resin (N=10) were subjected to thermal stress by using a thermocycling machine (TC301; Medical & Environmental Equipment Research Laboratory, Bangkok, Thailand) show as (figure 15). They were exposed to 5000 thermal cycles between5°C and 55°C with a 30-second dwell time at each temperature. These cycles of thermal stressing corresponded for 6 months of intraoral use.

Figure 15 Thermocycling machine (TC301; Medical & Environmental Equipment Research Laboratory, Bangkok, Thailand).

4. The10 specimens of non-thermal cycling (N=10) and thermal cycling group (N=10) in each group are subjected to Flexural strength test.

Repaired specimen preparation

1. The 320 specimens of heat-polymerized acrylic resin (ProBase Hot; Ivoclar Vivadent Inc.,Liechtenstein) were polymerized in stainless steel mold size 30.5x10x3.3mm (see figure 16) as the same method of the intact specimen of heat-polymerized acrylic resin.

Figure 16 Stainless steel mold dimension 30.5x10x3.3mm.

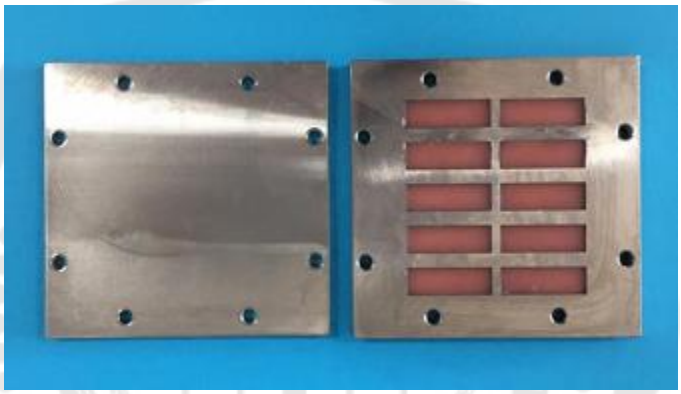


Figure 17 Specimens of repair group after polymerization

2. All specimens (figure 17) are finished in dimension (figure 18) by Automatic grinding and polishing machine with 400,600,800-grit silicon carbide paper retrospectively.

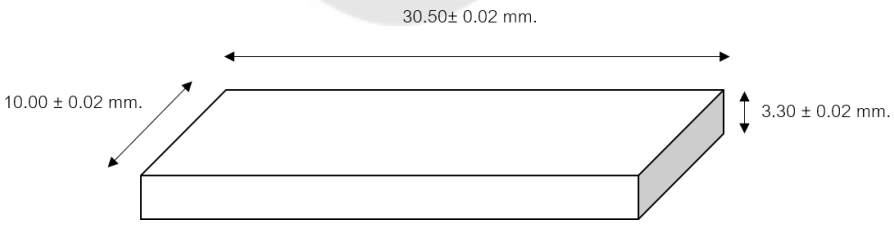


Figure 18 dimension of specimen for repaired group.

3. One end of the specimen is prepared to 45˚ bevel joint that ground with carbide bur (CX79.HP045; JOTA, Switzerland) and micromortor (micromotro; SAESHIN, Precision Co., Ltd, Korea) (figure 19) by using stainless-steel bevel jig 45˚ (figure 20) for guide plane.

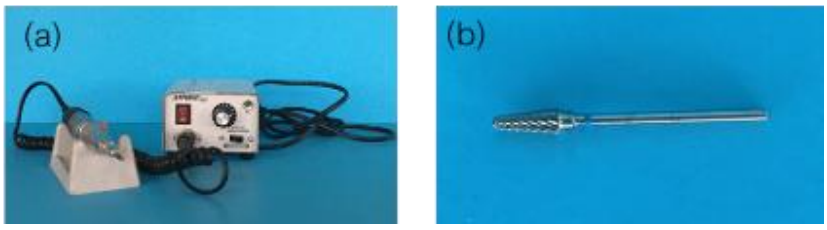


Figure 19 (a) micromortor (micromotro; SAESHIN, Precision Co., Ltd, Korea), (b) carbide bur (CX79.HP045; JOTA, Rüthi, Switzerland)

Figure 20 Bevel 45˚ with a stainless-steel bevel jig 45˚.

4. All specimens are randomly divided into four groups (80 per each group) that group 1 is repaired with Unifast Trad , group 2 is repaired with Ufi Gel hard, group 3 is repaired with Tokuyama Rebase II, group 4 is repaired with Kooliner.

5. Repair process by placing two pieces of the specimen in the Stainless-steel mold dimension 64x10x3.3mm (figure 21) that has been used to create intact specimen. The dimension of the specimens are retained by leave space between specimen 3 mm at the center of a stainless steel mold. (figure 21 and 22)

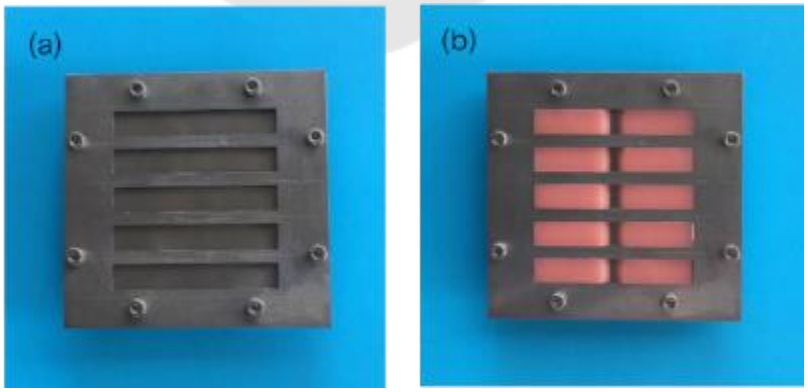


Figure 21 (a) stainless steel mold (dimension 64x10x3.3mm) and (b)Specimen place in stainless steel mold.

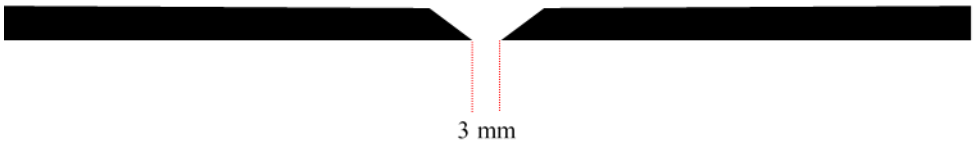


Figure 22 Space between specimens.

6. The repair material in each group is mixed according to the manufacturer's instruction and filling the gap with repair material that is slightly overfilled for polymerized shrinkage. (figure 23)

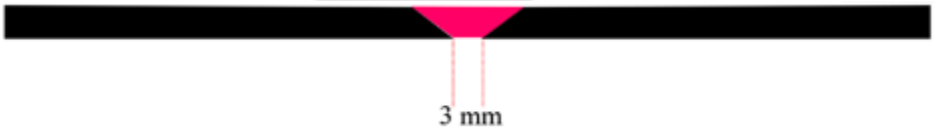


Figure 23 Filling the space with repair material.

7. After polymerization, specimens are removed, and finished in dimension (figure 24). A digital caliper (Vernier Digital Series 500-180-30; Mitutoyo, Japan) was used to evaluate the dimension of the specimen at three locations of each dimension to within 0.02 mm tolerance. These samples were stored in distilled water 37±1˚C for 50±2 hour before the test[21].

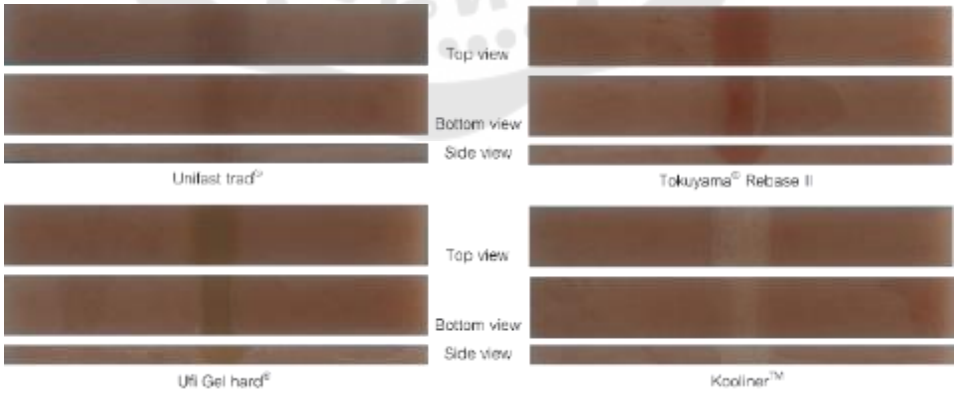


Figure 24 Repaired specimen

8. Each group consisted of 40 repaired specimens.

9. The 20 repaired specimens in each group (N=20) were subjected to thermal stress using a thermocycling machine. They were exposed to 5000 thermal cycles between5°C and 55°C with a 30-second dwell time.

Flexural strength test

1. Non-thermocycling group including the 10 intact specimens of heat-polymerized acrylic resin (N=10) and the 10 repaired specimens (N=10) in each group (Unifasr Trad, Ufi Gel hard, Tokuyama Rebase II, Kooliner).

2. Thermocycling group including the 10 intact specimens of heat-polymerized acrylic resin (N=10) and the 10 repaired specimens (N=10) in each group (Unifasr Trad, Ufi Gel hard, Tokuyama Rebase II, Kooliner) that were thermocycled by thermocycling machine.

To determine flexural strength, fracture load was measured using a three-point bending test on a universal testing machine (Universal testing machine: EZ Test Series, Shimadzu, Kyoto, Japan)(figure 25). The specimens were placed on a three-point flexure apparatus in which all rods are 5 mm in diameter with a 50 mm distance between two supports. A 1000 N load cell was applied at the midpoint of the repaired area with a crosshead speed of 5 mm/min until the specimen fractured. Fracture load was recorded. The flexural strength (MPa) was calculated according to the following formula.

$$FS=3FL/2bh2$$

FS = The flexural strength (MPa)

F = The maximum load (N)

L = The span distance (mm)

b = The width (mm) of the specimen

h = The height (mm) of the specimen

Figure 25 Flexural strength test.

Tensile bond strength test

1. Non-thermocycling group including the 10 repaired specimens (N=10) in each group (Unifasr Trad, Ufi Gel hard, Tokuyama Rebase II, Kooliner).

2. Thermocycling group including the 10 repaired specimens (N=10) in each group (Unifasr Trad, Ufi Gel hard, Tokuyama Rebase II, Kooliner) that they were thermocycled by thermocycling machine.

Specimens were tested in a universal testing machine (Universal testing machine: LR10K, LLOYD Instrument, England) (figure 26)at a crosshead speed of 1 mm/min, load cell 10,000 N until the specimens start to fracture. The tensile bond strength (MPa) was calculated according to the following formula.

TBS=F/D

TBS = The tensile bond strength (MPa)

F = The force (N)

D = The cross-sectional area (mm^2)

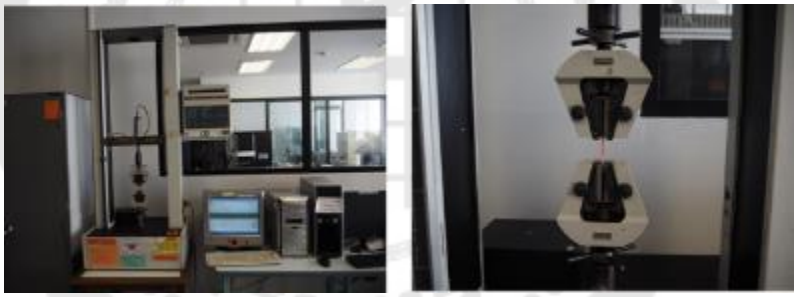


Figure 26 Tensile bond strength test.

Mode of failure

After the specimen is performed with flexural strength test or tensile strength test, the fractured area of the specimen is examined by Stereomicroscope (Olympus. SZ61; Olympus Optical Co., Tokyo, Japan)(figure 27) at X10 magnification to determine the failure type that is described to three types including;

1. Cohesive failure when fractures occur in repairing material or denture base material.. (figure 28)

2. Adhesive failure when fractures occur between the interface of denture base material and repairing material. (figure 29)

3. Mixed failure when fractures occur in both the repairing material and interface of denture base material. (figure 30)

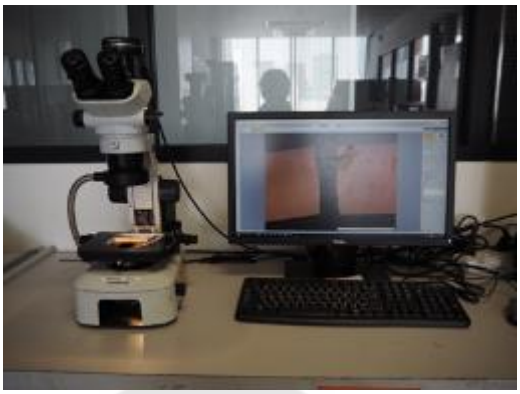


Figure 27 Stereo Microscope; Olympus. SZ61; Olympus Optical Co., Tokyo, Japan

Figure 28 Cohesive failure: (a) occured at repair materials, (b).occured at denture base material

Figure 29 Adhesive failure.

Figure 30 Mixed failure.

Intact specimen of of heat-polymerized acrylic resin and hard reline material preparation for SEM (Scanning Electron Microscopy)

1.The specimens of Unifast Trad (GC Dental Corperation, Japan) Ufi Gel hard (VOCO GmbH, Germany), Tokuyama Rebase II (Tokuyama Dental Corporation, Japan), Kooliner (GC Dental Corperation, Japan) were polymerized in a stainless steel mold (64x10x3.3 mm) by applying a thin coat of separating medium on the inner surface of the stainless steel mold. The materials were mixed according to the manufacturer's instructions. After polymerization, specimens were removed and

finished in a dimension (see Figure 31). These samples were then stored in distilled water 37±1˚C for 50±2 hours.

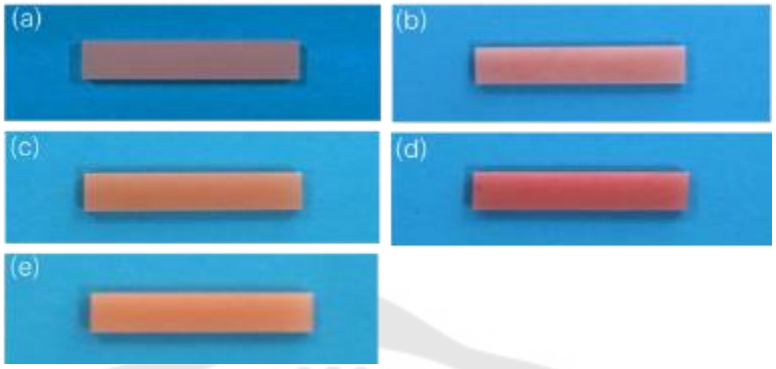


Figure 31 Specimens in the study: (a) ProBase Hot, (b) Unifast Trad, (c) Ufi Gel hard, (d) Tokuyama Rebase II, and (e) Kooliner

2. The specimens were broken by three-point bending on a universal testing machine (Universal testing machine: EZ Test Series, Shimadzu, Kyoto, Japan) and then placed on a three-point flexure apparatus with a distance of 50 mm between the two supports. A 1000 N load cell was applied at the midpoint of the repaired area with a crosshead speed of 5 mm/min.

3. The surface of the specimens was coated with a layer of gold at a thickness of 20 mm (see Figure 32), using the auto fine coater (see Figure 33b). The microstructure of the fracture surface was observed using Scanning Electron Microscopy (SEM; see Figure 33a) at 10 kV. The SEM images were collected using 500✕ and 3000✕ magnification for visual inspection.

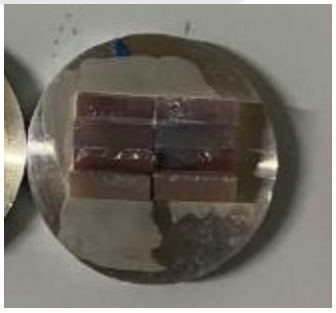


Figure 32 The specimens were coated with a layer of gold

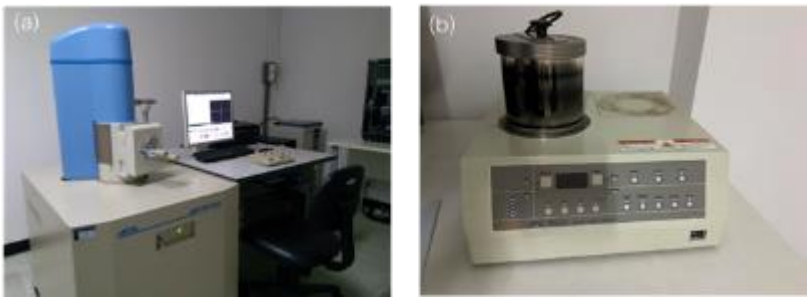


Figure 33 (a) Scanning Electron Microscopy (SEM): JSM-5410LV, JEOL, Japan, (b) Auto Fine Coater: JFC1600, JEOL, Japan

Statistical analysis

The statistical analysis was done by SPSS version 20.0 (IBM SPSS Statistics for Windows, Version 20.0, NY, USA). Normality of the data was determined Kolmogorov–Smirnov test. The homogeneity of variances was carried out by using Levene's test. two-way analysis of variances (ANOVA) was applied to analyze all data at P-value less than 0.05. Although the resuly did not follow with assumptions of Two-way analysis of variances, previously studies suggested ANOVA is robustness to violation of assumption of ANOVA.[38-40] Bonferroni post hoc test was used for comparing the mean of flexural strength of each repaired groups at P-value less than 0.05.

CHAPTER 4
RESULT

Flexural strength

The mean flexural strength and standard deviation of each group were shown in Table 7. The two-way ANOVA revealed that the material factor was significant, but thermocycling condition and their interaction were not ($P<0.05$). The flexural strength of the intact specimen was significantly higher than all groups. While in the repaired group, Unifast Trad was significantly better than all repaired groups, follow by Ufi Gel hard, Kooliner, and Tokoyama Rebase II, respectively. Ufi Gel hard group was significantly better than Tokuyama Rebase II and Kooliner. Tokuyama Rebase II was not significantly different from Kooliner ($P<0.05$).

After the thermocycling procedure, Flexural strength of the intact specimen increase from the non-thermocycling group, but there was no significant difference. In the repaired group, almost all the flexural strength values are decrease except Tokuyama Rebase II. The high flexural strength of the repaired group is Unifast Trad follow by Ufi Gel hard group, Tokuyama Rebase II, and kooliner, respectively. Unifast Trad was significantly better than all repaired groups. Ufi Gel hard group was significantly better than Tokuyama Rebase II and Kooliner. Tokuyama Rebase II was no significantly different from Kooliner. The flexural strength of repaired materials was not found significantly different between before and after Thermocycling except Unifast Trad.

Table 7 Mean values average and standard deviation of Flexural strength test

Repair materials	Flexural strenght (MPa)($\bar{X}$(S.D.))	
	Non-thermocycling	Thermocycling
Intact	95.60 (8.89)a	96.54(10.52)a
Unifast Trad	40.44 (8.14)	30.89 (4.49)
Ufi Gel hard	24.87 (5.11)b	23.74 (5.38)b
Tokuyama Rebase II	11.47 (2.26) Ac	13.49 (3.47) Bc
Kooliner	15.09 (1.65)Ad	13.44 (2.89)Bd

Vertically, Identical capital letters indicate no significant differences ($P>.05$) among repair materials.

Horzontally, Identical small letters indicate no significant differences ($P>.05$) between Non-thermocycling repair and thermocycling group.

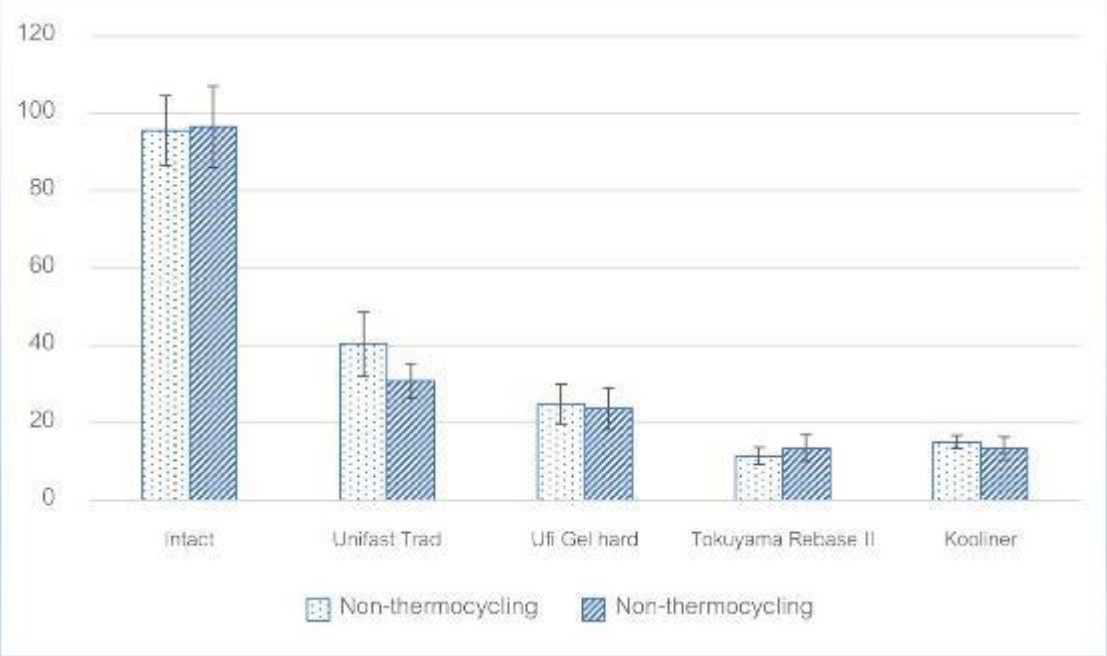


Figure 34 Mean values average of Flexural strength test

Tensile bond strength

The mean tensile bond strength and standard deviation of each group were shown in Table 8. The two-way ANOVA revealed that the main factor (material and thermocycling condition) and their interaction were significant was significant ($P<0.05$). Tensile bond strength of repaired with Unifast Trad was higher than all group in non-thermocycling condition follow with Ufi Gel hard group, Kooliner, and Tokuyama Rebase II, respectively. The two-way ANOVA found Unifast Trad was not significantly different from Ufi Gel hard group. In contrast, they were significantly better than Tokuyama Rebase II and Kooliner. Tokuyama Rebase II group was significantly different from Kooliner group.

After the thermocycling procedure, The tensile bond strength of almost all groups is decreased from the non-thermocycling group except tokuyama rebase II group. The high tensile bond strength is Unifast group follow with Ufi Gel hard group, Kooliner group, and Tokuyama Rebase II group, respectively. No significant differences in tensile bond strength were found between Unifast Trad with Ufi Gel hard. The tensile bond strength of repaired materials was found significantly different between before and after Thermocycling in Unifast Trad and Ufi Gel hard group ($P<0.05$), whereas Tokuyama Rebase II and Kooliner were not significantly different ($P<0.05$).

Table 8 Mean values average and standard deviation of tensile bond strength test

Repair materials	Tensile bond strenght (MPa)($\bar{X}$(S.D.))	
	Non-thermocycling	Thermocycling
Unifast Trad	22.85 (5.05)A	18.76 (4.85)B
Ufi Gel hard	21.38 (6.88)A	15.39 (4.67)B
Tokuyama Rebase II	5.76 (1.59)a	7.73 (1.42)Ca
Kooliner	11.12 (2.76)b	9.54 (2.18)Cb

Vertically, Identical capital letters indicate no significant differences (*P*>.05) among repair materials.

Horzontally, Identical small letters indicate no significant differences (*P*>.05) between Non-thermocycling repair and thermocycling group.

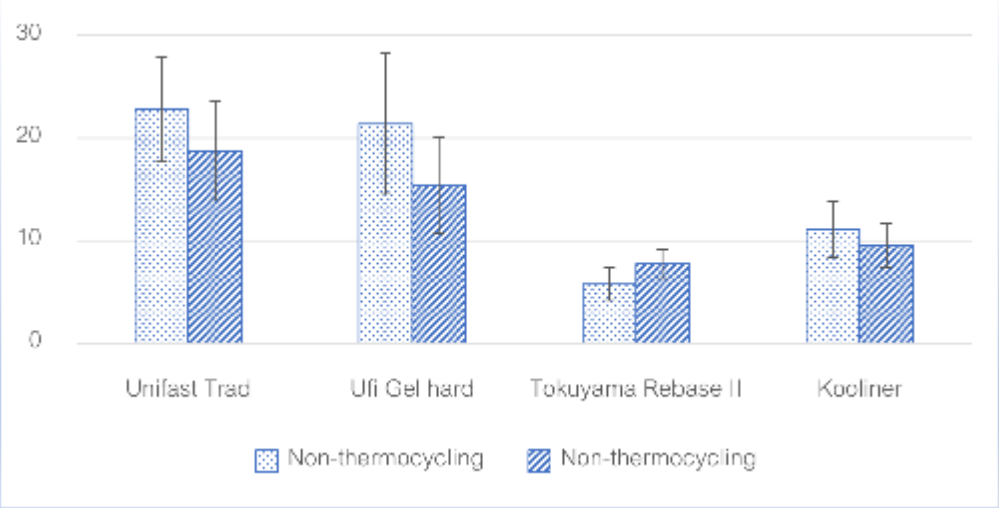


Figure 35 Mean values average of Tensile bond strength test

Mode of failure

Flexural strength

Mode of failure are presented in Table 9. Unifast Trad has found almost cohesive failure (figure 33). The mode of failure of Ufi Gel hard was all cohesive failure(figure 34). Tokuyama Rebase II has found cohesive, mix failure and adhesive failure(figure 35). While, Kooliner has found mix failure more than adhesive failure(figure 36). After thermocycling process, Unifast Trad, Ufi Gel

hard and Kooliner are similar failure mode to Non-thermocycling group except Tokuyama Rebase II, There was found most mix failure type.

Table 9 Failure mode of Flexural strength group

Repair materials	Mode of failure					
	Non-thermocycling			Thermocycling		
	Cohesive	Adhesive	Mix	Cohesive	Adhesive	Mix
Unifast Trad	90% (9)	0% (0)	10% (1)	80% (8)	0% (0)	20% (2)
Ufi Gel hard	100% (10)	0% (0)	0% (0)	100% (10)	0% (0)	0% (0)
Tokuyama Rebase II	40% (4)	20% (2)	40% (4)	30% (3)	0% (0)	70% (7)
Kooliner	0% (0)	30% (3)	70% (7)	0% (0)	40% (4)	60% (6)

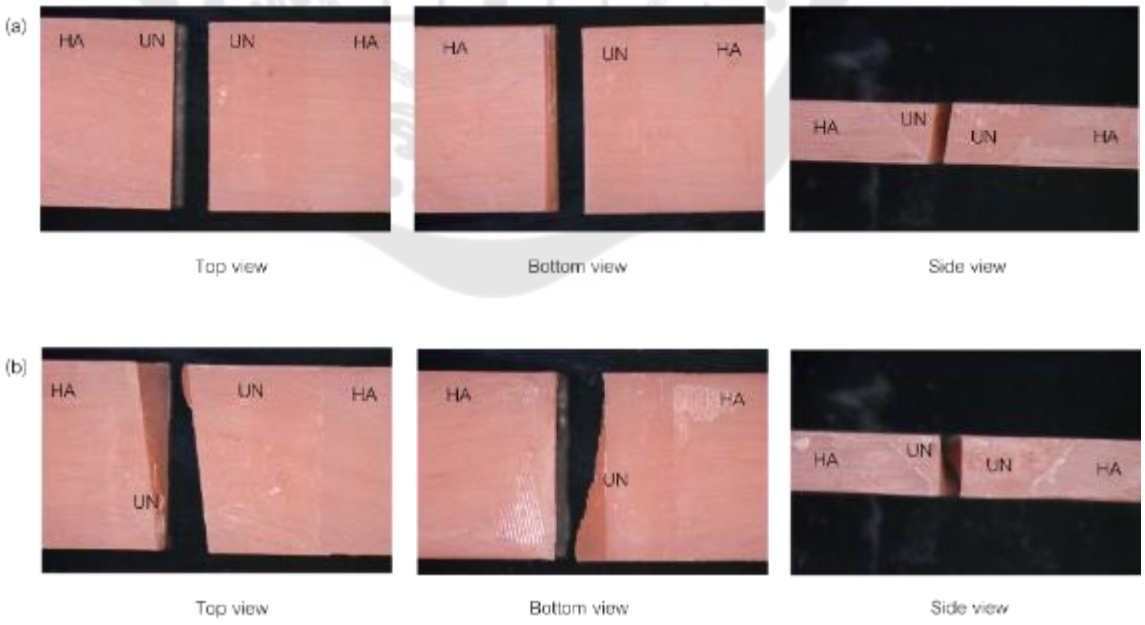


Figure 36 Unifast Trad: Stereomicroscopic picture of bonding interface showing cohesive failure(a) and mix failure(b)

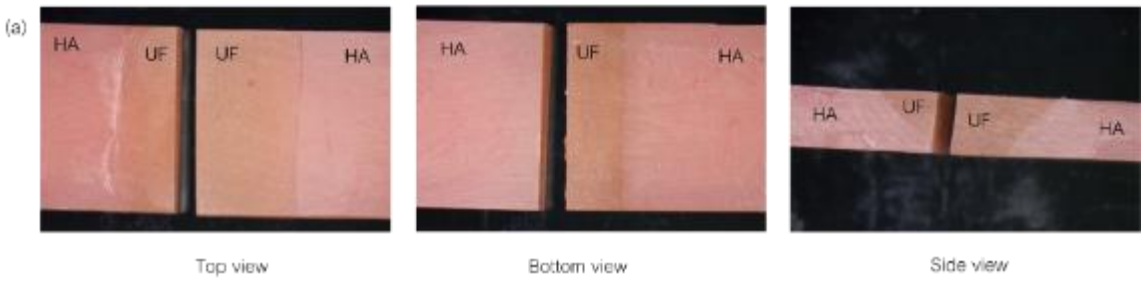


Figure 37 Ufi Gel hard: Stereomicroscopic picture of bonding interface showing cohesive failure(a)

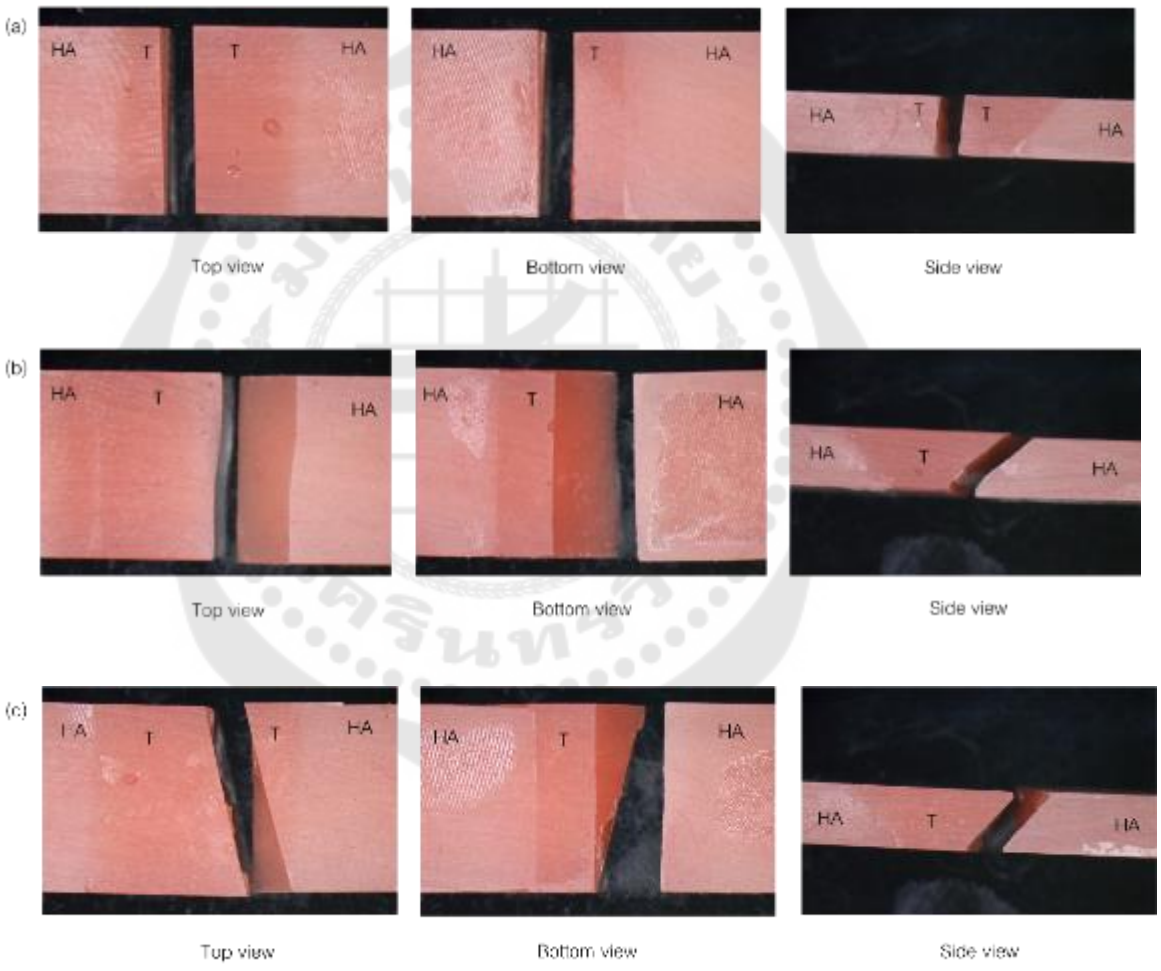


Figure 38 Tokuyama Rebase II: Stereomicroscopic picture of bonding interface showing cohesive failure(a) ,adhesive failure (b)and mix failure(c)

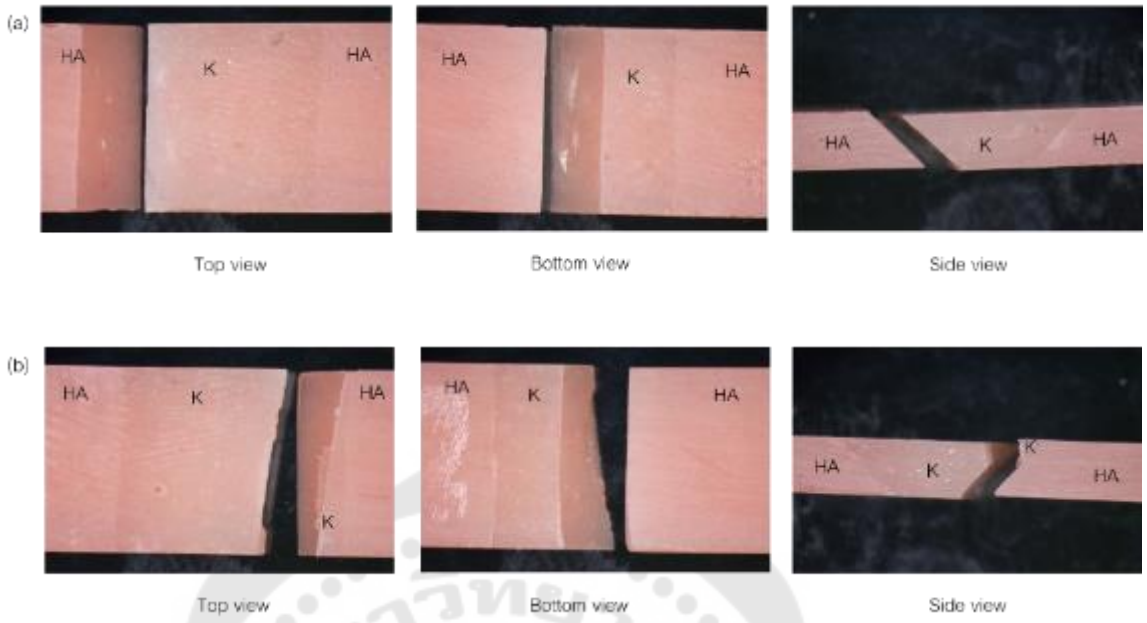


Figure 39 Kooliner: Stereomicroscopic picture of bonding interface showing adhesive failure (a)and mix failure(b)

Tensile bond strength test

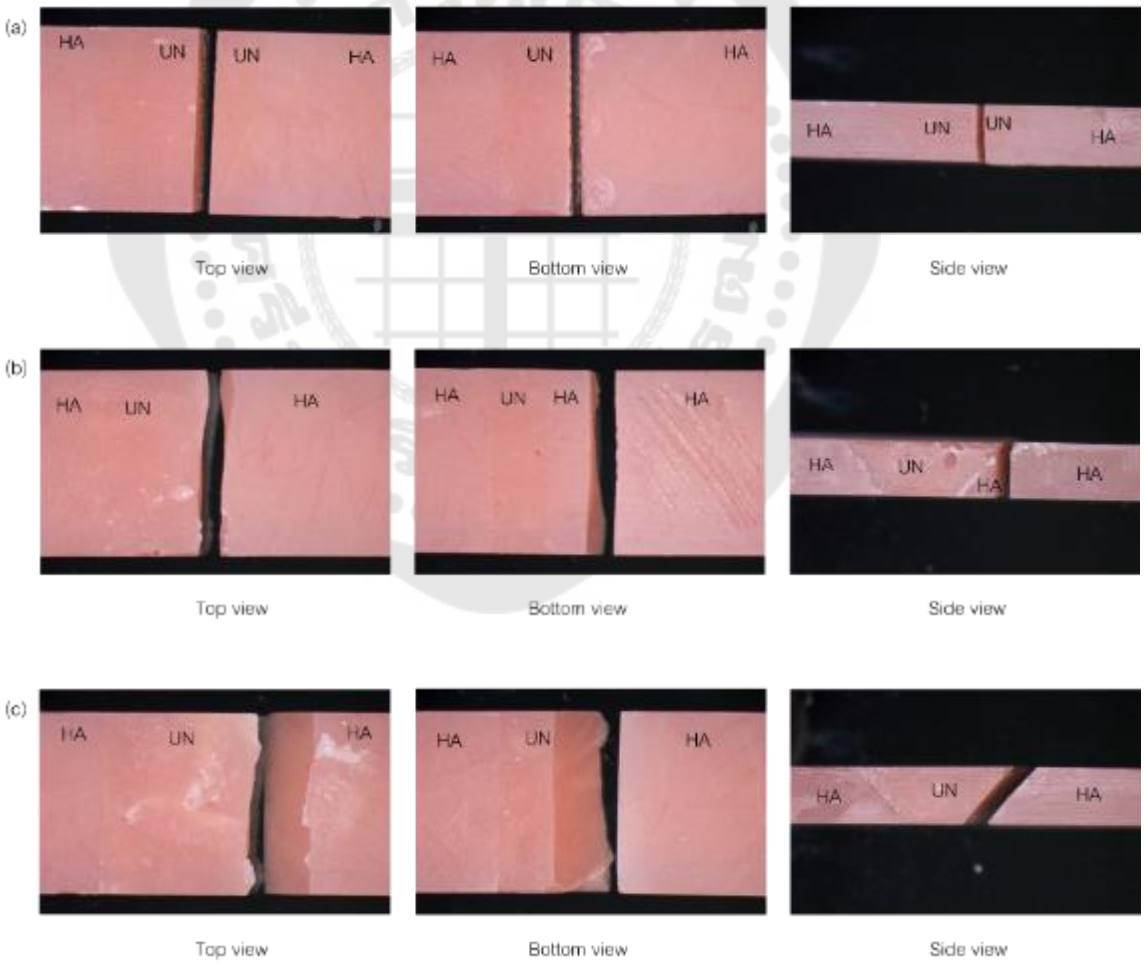
Failure mode of tensile bond strength are presented in Table 10. Cohesive failure are most common found on Unifast Trad (figure 37) and Ufi Gel hard (figure 38). Furthermore, in cohesive failure group of Unifast trad has found 3 specimens were fractured at denture base material (figure 37). While there has found mix failure in Tokuyama rebase II (figure 39) and Kooliner(figure 40). After thermocycling all material are show failure type similar Non-thermocycling group except Unifast Trad, which show most mix failure type.

Table 10 Failure mode of Tensile bond strength group

Repair materials	Mode of failure					
	Non-thermocycling			Thermocycling		
	Cohesive	Adhesive	Mix	Cohesive	Adhesive	Mix
Unifast trad	90% (9)	0% (0)	10% (1)	40% (4)	10% (1)	50% (5)
Ufi Gel hard	90% (9)	0% (0)	10% (1)	100% (10)	0% (0)	0% (0)

Table 10 Continue

Repair materials	Mode of failure					
	Non-thermocycling			Thermocycling		
	Cohesive	Adhesive	Mix	Cohesive	Adhesive	Mix
Tokuyama Rebas II	0% (0)	0% (0)	100% (10)	20% (2)	0% (0)	80% (8)
Kooliner	0% (0)	30% (3)	70% (7)	0% (0)	30% (3)	70% (7)



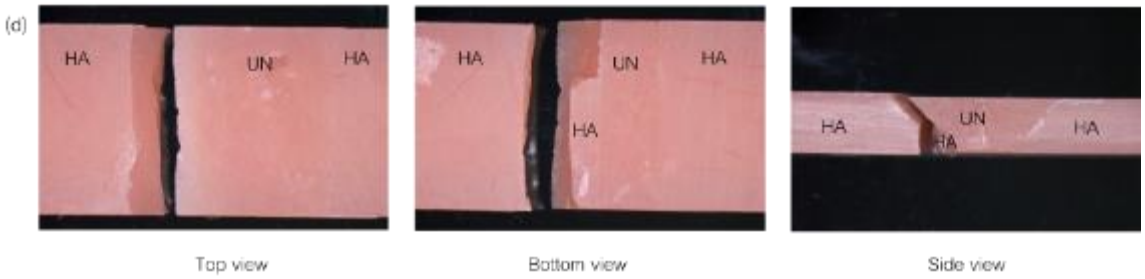


Figure 40 Unifast Trad: Stereomicroscopic picture of bonding interface showing cohesive failure(a) and(b) ,adhesive failure (c), and mix failure(d)

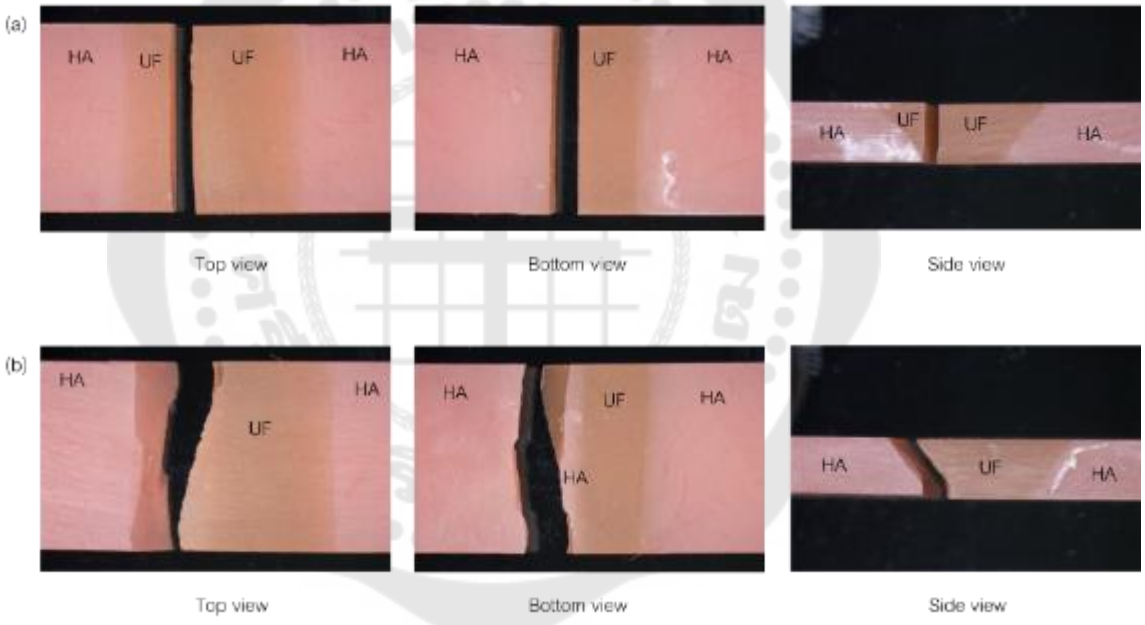


Figure 41 Ufi Gel hard: Stereomicroscopic picture of bonding interface showing cohesive failure(a) and mix failure(b)

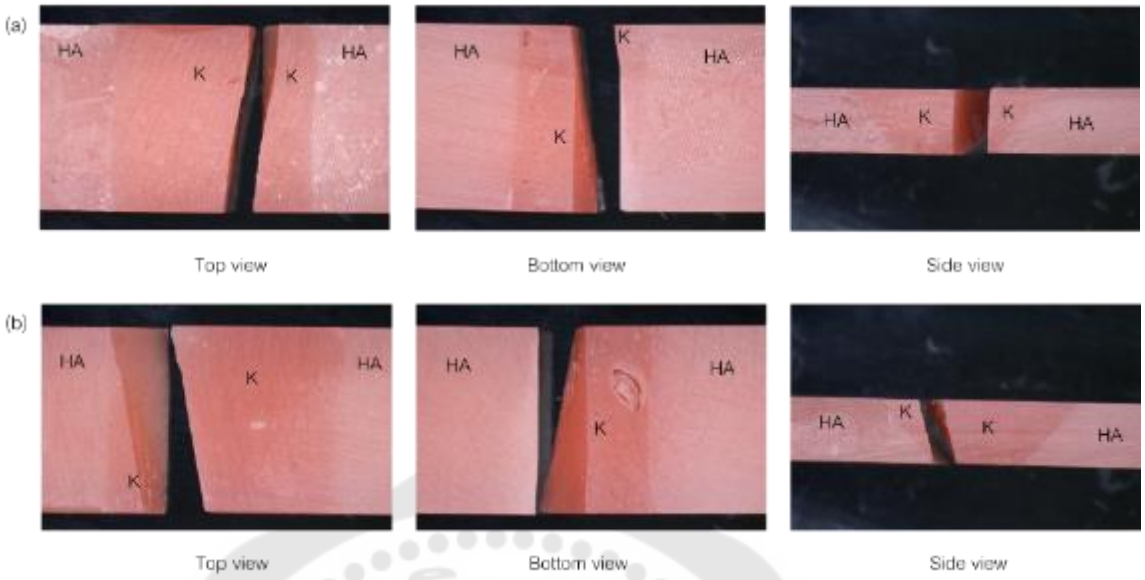


Figure 42 Tokuyama Rebase II: Stereomicroscopic picture of bonding interface showing cohesive failure(a) and mix failure(b)

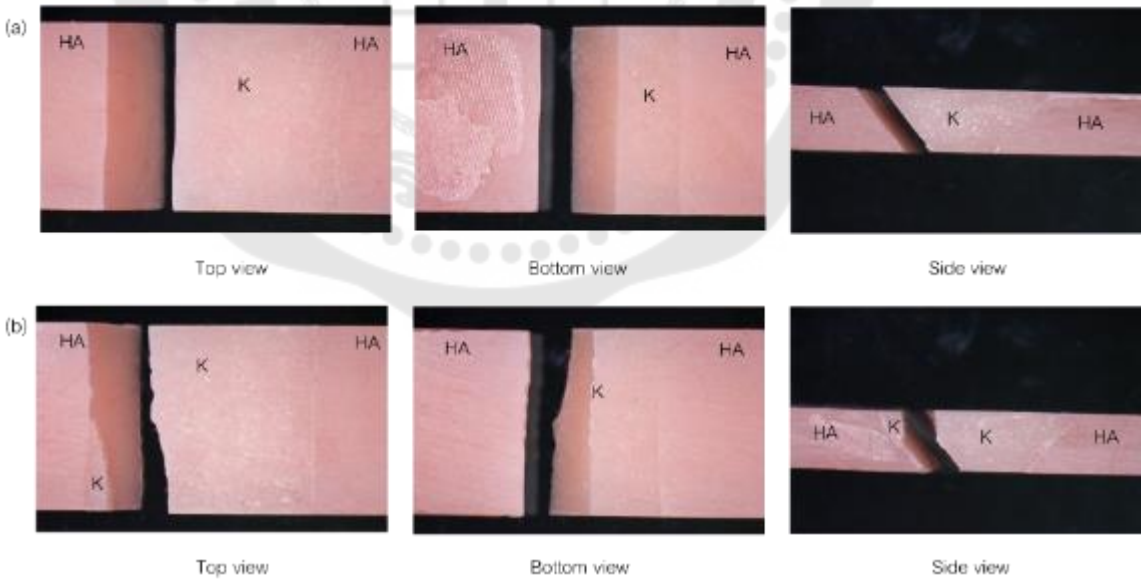


Figure 43 Kooliner: Stereomicroscopic picture of bonding interface showing adhesive failure(a) and mix failure(b)

The Scanning Electron Microscopy (SEM)

According to the SEM observation, the fracture surface of the specimens in ×500 magnification and ×3000 magnification showed. The SEM images of all materials showed a network polymer structure. The SEM image of ProBase Hot (Figure 4) showed filament structures in the matrix polymers, while the SEM images of all hard reline materials (see Figures 5-8) showed granular microstructures that were clearly distinguishable when bound together in a matrix. In particular, Unifast Trad and Tokuyama Rebase II showed clear granular structures over matrix polymers, whereas Ufi Gel hard and Kooliner seem more similar. Moreover, the size of the granular structure varied across each material. Ufi Gel hard's polymer bead is typically larger than other hard reline materials.

In this study, the SEM image of Unifast Trad was similar to the SEM image of Tokuyama Rebase II. In the hard reline material group, Kooliner has a larger fracture line (red arrow) than all other hard reline materials, while Ufi Gel hard revealed the smallest fracture line.

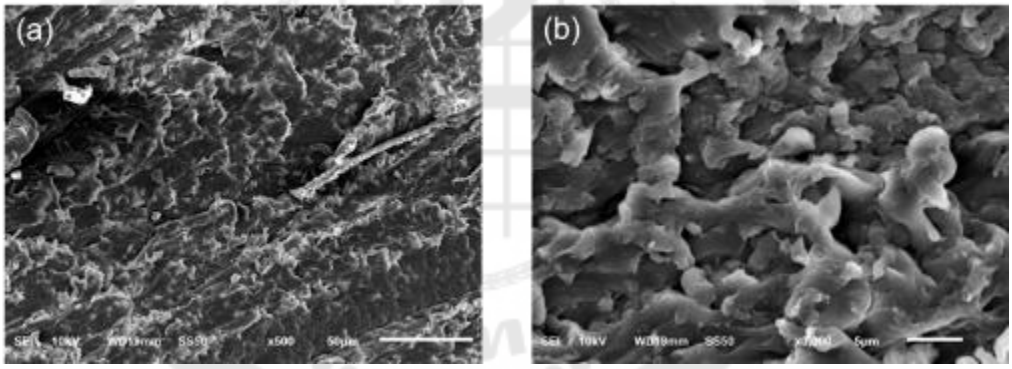


Figure 44 SEM images of ProBase Hot; (a) at 500× and (b) at 3000× magnification

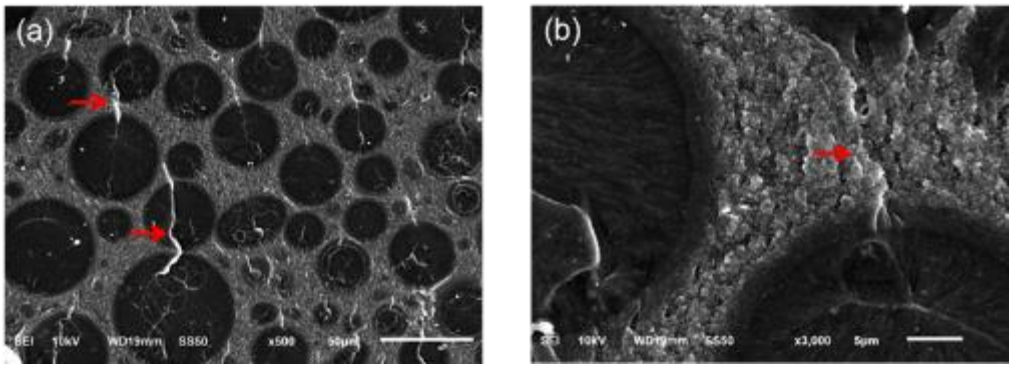


Figure 45 SEM images of Unifast Trad; (a) at 500× and (b) at 3000× magnification

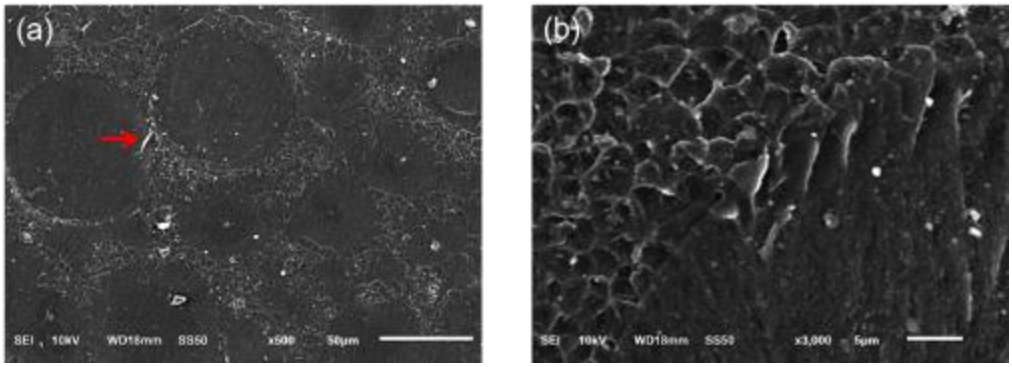


Figure 46 SEM images of Ufi Gel hard; (a) at 500✕ and (b) at 3000✕ magnification

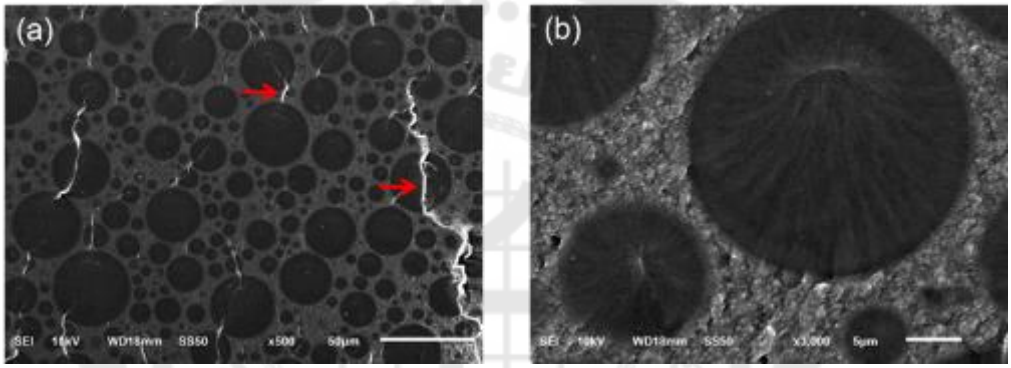


Figure 47 SEM images of Tokuyama Rebase II; (a) at 500✕ and (b) at 3000✕ magnification

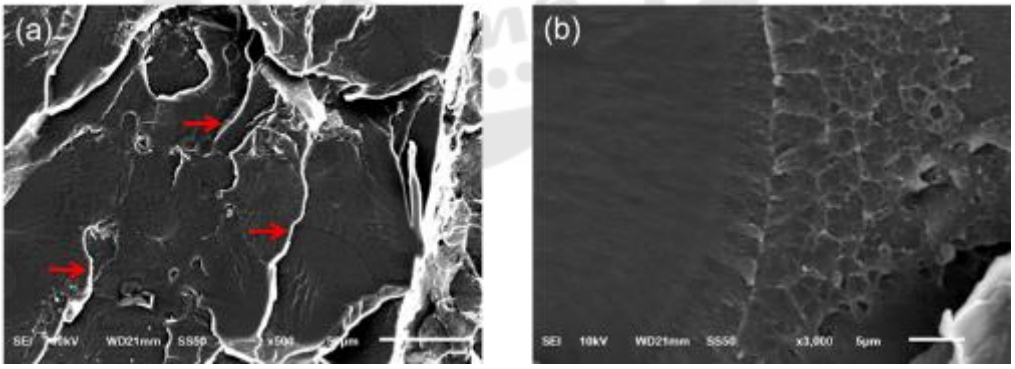


Figure 48 SEM images of Koliner; (a) at 500✕ and (b) at 3000✕ magnification

CHAPTER 5
DISCUSSION

The purpose of this study was to evaluate the mechanical properties on flexural strength and tensile bond strength of repaired denture base material with three commercially non-MMA based hard reline materials and one auto-polymerized acrylic resin before and after thermocycling. The Denture base material in this study is ProBase Hot, which is Heat polymerized acrylic resin. The non-MMA based hard reline materials were selected in the study, including Ufi Gel hard, Tokuyama Rebase II, and Kooliner. At the same time, Unifast Trad was selected to represent the MMA base auto-polymerized acrylic resin. All repair materials are auto-polymerized acrylic resin, which has been studied mechanical properties as in relining material[8, 13, 17, 19, 41] and repair material[15]. Although previous studies have been reported the mechanical properties of those materials, there have been a few investigations in thermocycling conditions.

The mechanical properties of repaired denture base materials have been evaluated by many methods, including Flexural strength test, shear bond strength test, torsional test, and tensile bond strength. This study has interested in the flexural strength and tensile bond strength. The flexural strength test has been evaluated repaired denture materials in this study follow with the method which was described by ISO 20795-1 2013.[21] In contrast, there is no standard method for evaluating tensile bond strength. Mutluay et al.[8] suggested that tensile bond strength test applies a simple tensile force to the joint, which allows for comparison among different materials. in this Previous investigations were used the method in a different dimension of specimen.[8, 17, 31]

MMA base auto-polymerized acrylic resin has been used for a long time as a relining and repair material. Direct reline technique, using with MMA base auto-polymerized acrylic reline direct contact to oral tissue of patients. This method's advantage is easy to use, time-saving, and cost-saving, but the disadvantage is bad taste, bad odor, heat during the process, irritating soft tissue, and allergic to the patient and dental personnel. Hence, non-MMA based hard reline materials were introduced to solve these problems. Non-MMA based hard reline materials have a different composition from denture base material. The main composition of the polymer is PEMA. Moreover, there is various monomer type, which is generally higher molecular weight than MMA monomer.

In this study, the result (table 7) revealed that flexural strength of Unifast Trad was statistically significantly higher than all repaired groups. However, their flexural strength means value was still lower than the intact specimens group. In the repaired group of non-MMA based hard reline materials, the highest flexural strength is Ufi Gel hard, followed by Tokuyama Rebase II and Kooliner. Ufi Gel hard group was significantly better than Tokuyama Rebase II and Kooliner. Tokuyama

Rebase II was no significantly different from Kooliner ($P<0.05$). Similarly, result as Kanchanavasita et al.[15] that evaluated flexural strength of repaired acrylic denture base material with non-MMA base hard reline materials to compare with repaired denture base material with the auto-polymerized acrylic resin that they found Unifast Trad has the highest flexural strength in another non-MMA base hard reline materials, but this study did not evaluate Ufi Gel hard. Hout et al.[42] evaluated flexural strength of reline material (Unifast Trad, Tokuyama Rebase II, and Kooliner) on the heat-polymerized acrylic resin in different thicknesses and found the highest flexural strength in Unifast Trad follow with Kooliner and Tokuyama Rebase II. Although Tokuyama Rebase II has a cross-link agent and adhesive agent but flexural strength lower than Kooliner.[42]

Whereas in the tensile bond strength test, the result (table 8) revealed that the tensile bond strength of Unifast Trad showed tensile bond strength that higher than all group, follow by Ufi Gel hard Kooliner and Tokuyama Rebase II, respectively. Although Unifast Trad showed the highest tensile bond strength, there was no significant difference from Ufi Gel hard. Similar to Neppelenbroek et al. that revealed Ufi Gel hard had the highest shear bond strength among reline materials (Kooliner, Duraliner II, Tokuso Rebase).[13] Conversely, this study's bonding area is a bevel joint that not perpendicular to the tensile force. While bonding area of the tensile bond strength test in previous studies is the butt joint.[8, 17]

The strength of repaired specimens depends on the volume of material, the strength of the materials, and bonding properties to each other of materials.[16] This study used 3 mm. in gap width because the previous study has described gap width less than or equal to 3 mm is decreased polymerization shrinkage of repair material and difference of color between a repair material and acrylic denture base.[34] Whereas bonding properties depend on bond strength between the denture base and repaired material depend on interpenetarating polymer network (IPN), resulting from the diffusion, penetration, and polymerization of monomer in denture base structure.[41] Previous studies reported the low molecular weight monomer leads to greater IPN than the high molecular weight monomer. Accordingly, the monomer of hard relining material infiltrates slower infiltrate to PMMA denture base material than MMA monomer because non-MMA hard reline materials have a large molecular weight than MMA monomer. Previously has reported Unifast Trad (MMA=100.12) has a lower molecular weight than Ufi Gel hard (1,6 HDMA=254.33), Tokuyama Rebase II (1,9-NDMA=296.40, AAEMA=214.20), or Kooliner (IBMA=142.20).[8, 31, 43]

Ufi Gel hard and Tokuyama Rebase II monomer contained 1,6 HDMA that molecular weight higher than MMA monomer, but Ufi Gel hard's adhesive contains 2-HEMA (Molecular weight=130.14) and acetone (Molecular weight=58.05), 2-HEMA is a monomeric bonding agent, which has revealed excellent wetting and swelling agent result in great IPN formation.[8, 41] While, acetone is low molecular

weight solvent that promoted to softening denture base surface. Tokuyama Rebase II adhesive contains ethyl acetate (Molecular weight=88.11)and acetone, but less strength than Ufi Gel hard. The previous study[42] noted that that the effect of ethyl acetate and acetone contained in Tokuyama Rebase II had not been confirmed. In contrast, Kooliner does not have an adhesive agent, but a previous study has suggested MMA monomer as an adhesive agent for Kooliner, resulting in improve bond strength.[33]

Thermal cycling simulates the oral conditions. The process is performed between 5 °C and 55 °C for 5,000 cycles with a dwell time of 30 seconds, representing acrylic denture use of 6 months. The process was performed between 5°C and 55°C for 5,000 cycles with a dwell time of 30 seconds.[32] A previous study reported water penetrated to the denture base polymer structure and then separate the polymer chain, expanding of polymer mass. Besides, water can also act as a plasticizer that is also affected to mechanical properties.[18]Whereas heat increases space between polymer chain of denture base material result in increased water absorption.[18] Whatmore, Thermal cycling contributes to contraction and expansion of denture base material and repair material, which have a difference in coefficient of thermal expansion.[16] In this study, flexural strength and tensile bond strength value of almost all of the repaired materials were reduced except Tokuyama rebase II. Because Tokuyama Rebase II maybe continue polymerized and released monomer, which acts as a plasticizer.[13]

Both studies (Flexural strength and Tensile bond strength test) has found Unifast Trad was significantly different by thermocycling, while Tokuyama Rebase II and Kooliner were not significantly different by thermocycling. Ufi Gel hard was significantly different by thermocycling in the tensile bond strength test. The previous report described a high percentage of the cross-link agent in material shows low water sorption.[19] Ufi Gel hard and Tokuyama Rebase II consist of cross-linking agents, which improved mechanical strength properties.[16] Because cross-linking agent was bonded atoms between polymers chains. Moreover, many studies reported that cross-link agents are also diffusion to the surface of PMMA, which results in improve bond strength.[8] In conversely, the previous study pointed out that cross-link agent maybe limit the function of monomer to bond with denture base materials.[16]

The mode of failure of these tests was a similar result (table8, table9). The study revealed Unifast Trad and Ufi Gel hard were a mostly cohesive failure, whereas Tokuyama Rebase II and Kooliner were a mixed failure. In the group of adhesive failure, Kooliner has found most, which similar to the previous study.[19] Kooliner has no adhesive primer, which promotes bonding to denture base material.[19] In addition, in tensile bond strength study that has found cohesive failure at denture base material in Unifast Trad group. The previous research described cohesive failure represents a

material with a strong bond more than the cohesive strength of repair or denture base material.[8] On the other hand, Kanchanavasita et al.[15]have studied flexural strength of denture base material repaired with auto polymerized reline material (Unifast trad, Tokuyamarebase II, and Kooliner) and reported the most result of all material were an adhesive failure.

Previous studies[44] suggest that investigating microstructures of the denture material may help to determine the cause of failure. Nevertheless, there are very few studies that have used SEM to investigate denture base material fractures.[44, 45]In this study, the results revealed that the SEM image of ProBase Hot (Heat-cured acrylic resin) is different from the other hard reline materials. All hard reline materials showed bead structures in the polymer matrix. In the SEM images of fractured hard reline materials, we found fracture lines in the surface of the material. The largest ones were found with Kooliner.

The purpose of the study investigated the mechanical properties of non-MMA reline material on denture repair materials for the patient or dental personnel who allergic to MMA monomer. In the present study, mechanical properties (Flexural strength and tensile bond strength) of MMA base material has better than non-MMA base material. Except for the tensile bond strength value of Ufi Gel hard, which was not significantly different from Unifast Trad. Accordingly, non-mma base reline materials are not recommended as denture repair materials. The limitation of this study is in vitro study and is not the same as the denture shape. Further investigation is a method to improve the strength of Ufi Gel hard, which showed good tensile bond strength.

CONCLUSION

Unifast Trad exhibited the highest flexural strength and tensile bond strength among the repaired group, whereas Ufi Gel hard exhibited the highest flexural strength and tensile bond strength in the non-MMA group. Furthermore, the tensile bond strength value of Ufi Gel hard was not significantly different from Unifast Trad. Accordingly, From the clinical point of view from our study suggest that non-MMA based material (Ufi Gel hard) can be used as an alternative for the patient or dentist allergic to MMA monomer.

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APPENDIX

Table 11 The flexural strength value

Unit	Flexural strength (MPa)($\bar{X}$(S.D.))	
	Non-thermocycling	Thermocycling
IN_1	110.16	85.83
IN_2	93.54	111.31
IN_3	92.61	81.46
IN_4	103.31	103.48
IN_5	101.05	100.70
IN_6	95.52	107.09
IN_7	101.33	99.17
IN_8	79.01	102.86
IN_9	92.94	83.59
IN_10	86.59	89.93
Average	95.60	96.54
Standard Deviation	8.89	10.52
UN_1	38.15	27.38
UN_2	54.01	26.69
UN_3	41.58	38.40
UN_4	56.68	26.17
UN_5	35.40	28.89
UN_6	37.00	32.32
UN_7	36.00	29.65
UN_8	34.62	27.39
UN_9	34.42	35.28
UN_10	36.50	36.71
Average	40.44	30.89
Standard Deviation	8.14	4.49

Table 11 Continue

Unit	Flexural strength (MPa)($\bar{X}$(S.D.))	
	Non-thermocycling	Thermocycling
UF_1	32.37	25.57
UF_2	20.82	20.37
UF_3	19.00	25.69
UF_4	24.02	27.50
UF_5	27.31	19.35
UF_6	19.35	25.57
UF_7	21.59	35.48
UF_8	32.32	17.37
UF_9	29.25	19.16
UF_10	22.66	21.30
Average	24.87	23.74
Standard Deviation	5.11	5.38
T_1	9.33	10.80
T_2	11.26	15.75
T_3	14.12	22.40
T_4	11.52	11.45
T_5	10.31	13.10
T_6	12.04	10.78
T_7	8.16	13.52
T_8	15.31	11.81
T_9	9.44	12.02
T_10	13.20	13.22
Average	11.47	13.49
Standard Deviation	2.26	3.47

Table 11 Continue

Unit	Flexural strength (MPa)($\bar{X}$(S.D.))	
	Non-thermocycling	Thermocycling
K_1	16.37	10.19
K_2	13.64	15.05
K_3	13.14	11.28
K_4	13.98	9.83
K_5	13.38	13.95
K_6	16.48	11.33
K_7	17.94	17.23
K_8	14.15	13.17
K_9	16.48	18.42
K_10	15.34	13.96
Average	15.09	13.44
Standard Deviation	1.65	2.89

Table 12 The tensile bond strength

Unit	Tensile bond strength (MPa)($\bar{X}$(S.D.))	
	Non-thermocycling	Thermocycling
UN_1	19.78	23.13
UN_2	21.57	20.15
UN_3	22.49	19.40
UN_4	20.31	24.38
UN_5	25.36	10.25
UN_6	14.93	20.53
UN_7	18.13	19.06
UN_8	28.51	10.03
UN_9	31.88	21.21
UN_10	25.50	19.49
Average	22.85	18.76
Standard Deviation	5.05	4.85
UF_1	23.70	19.02
UF_2	17.44	19.61
UF_3	22.51	19.09
UF_4	24.60	10.28
UF_5	13.85	23.68
UF_6	29.82	14.80
UF_7	27.25	9.82
UF_8	11.22	12.25
UF_9	29.72	12.01
UF_10	13.72	13.35
Average	21.38	15.39
Standard Deviation	6.88	4.67

Table 12 Continue

Unit	Tensile bond strength (MPa)($\bar{X}$(S.D.))	
	Non-thermocycling	Thermocycling
T_1	5.59	7.49
T_2	5.23	7.08
T_3	4.37	10.48
T_4	5.91	5.82
T_5	5.84	7.71
T_6	7.51	8.06
T_7	4.15	8.55
T_8	4.81	7.02
T_9	9.38	9.14
T_10	4.78	5.97
Average	5.76	7.73
Standard Deviation	1.59	1.42
K_1	14.24	8.08
K_2	12.48	9.58
K_3	14.41	6.25
K_4	10.08	12.30
K_5	11.82	7.02
K_6	9.64	8.75
K_7	9.02	8.67
K_8	8.40	10.52
K_9	14.44	11.96
K_10	6.72	12.27
Average	11.12	9.54
Standard Deviation	2.76	2.18

STATISTICS ANALYSIS

Flexural strength test

Descriptive ststistic

Descriptive Statistics

Dependent Variable: Flexural strength

Repairing material	Thermocycling	Mean	Std. Deviation	N
Intact	Non thermocycling	95.6060	8.88599	10
	Thermocycling	96.5420	10.51607	10
	Total	96.0740	9.48771	20
UNIFAST Trad	Non thermocycling	40.4360	8.14460	10
	Thermocycling	30.8880	4.49216	10
	Total	35.6620	8.06046	20
Ufi Gel hard	Non thermocycling	24.8690	5.10539	10
	Thermocycling	23.7360	5.38105	10
	Total	24.3025	5.13812	20
Tokuyama Rebase II	Non thermocycling	11.4690	2.26408	10
	Thermocycling	13.4850	3.47125	10
	Total	12.4770	3.03404	20
Kooliner	Non thermocycling	15.0900	1.65437	10
	Thermocycling	13.4410	2.88814	10
	Total	14.2655	2.44197	20
Total	Non thermocycling	37.4940	31.57625	50
	Thermocycling	35.6184	32.00472	50
	Total	36.5562	31.64428	100

Test of normality

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Flexural strength	.247	100	.000	.751	100	.000

a. Lilliefors Significance Correction

Levene's Test of Equality of Error Variances

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

Dependent Variable: Flexural strength

F	df1	df2	Sig.
6.047	9	90	.000

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

a. Design: Intercept + Material + Thermo + Material * Thermo

Tests of Between-Subjects Effects

Tests of Between-Subjects Effects

Dependent Variable: Flexural strength

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	95900.627[a]	9	10655.625	296.536	.000
Intercept	133635.576	1	133635.576	3718.946	.000
Material	95400.089	4	23850.022	663.723	.000
Thermo	87.947	1	87.947	2.447	.121
Material * Thermo	412.591	4	103.148	2.870	.027
Error	3234.035	90	35.934		
Total	232770.237	100			
Corrected Total	99134.662	99			

a. R Squared = .967 (Adjusted R Squared = .964)

Pairwise Comparisons Dependent Variable

Repair materials

Pairwise Comparisons

Dependent Variable: Flexural strength

(I) Repairing material	(J) Repairing material	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
Intact	UNIFAST Trad	60.412*	1.896	.000	54.957	65.867
	Ufi Gel hard	71.772*	1.896	.000	66.316	77.227
	Tokuyama Rebase II	83.597*	1.896	.000	78.142	89.052
	Kooliner	81.808*	1.896	.000	76.353	87.264
UNIFAST Trad	Intact	-60.412*	1.896	.000	-65.867	-54.957
	Ufi Gel hard	11.359*	1.896	.000	5.904	16.815
	Tokuyama Rebase II	23.185*	1.896	.000	17.730	28.640
	Kooliner	21.396*	1.896	.000	15.941	26.852
Ufi Gel hard	Intact	-71.772*	1.896	.000	-77.227	-66.316
	UNIFAST Trad	-11.359*	1.896	.000	-16.815	-5.904
	Tokuyama Rebase II	11.826*	1.896	.000	6.370	17.281
	Kooliner	10.037*	1.896	.000	4.582	15.492
Tokuyama Rebase II	Intact	-83.597*	1.896	.000	-89.052	-78.142
	UNIFAST Trad	-23.185*	1.896	.000	-28.640	-17.730
	Ufi Gel hard	-11.826*	1.896	.000	-17.281	-6.370
	Kooliner	-1.789	1.896	1.000	-7.244	3.667
Kooliner	Intact	-81.808*	1.896	.000	-87.264	-76.353
	UNIFAST Trad	-21.396*	1.896	.000	-26.852	-15.941
	Ufi Gel hard	-10.037*	1.896	.000	-15.492	-4.582
	Tokuyama Rebase II	1.789	1.896	1.000	-3.667	7.244

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Thermocycling condition

Pairwise Comparisons

Dependent Variable: Flexural strength

(I) Thermocycling	(J) Thermocycling	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Non thermocycling	Thermocycling	1.876	1.199	.121	-.506	4.257
Thermocycling	Non thermocycling	-1.876	1.199	.121	-4.257	.506

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Repair materials * Thermocycling condition

Pairwise Comparisons

Dependent Variable: Flexural strength

Thermocycling	(I) Repairing material	(J) Repairing material	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
						Lower Bound	Upper Bound
Non thermocycling	Intact	UNIFAST Trad	55.170*	2.681	.000	47.455	62.885
		Ufi Gel hard	70.737*	2.681	.000	63.022	78.452
		Tokuyama Rebase II	84.137*	2.681	.000	76.422	91.852
		Kooliner	80.516*	2.681	.000	72.801	88.231
	UNIFAST Trad	Intact	-55.170*	2.681	.000	-62.885	-47.455
		Ufi Gel hard	15.567*	2.681	.000	7.852	23.282
		Tokuyama Rebase II	28.967*	2.681	.000	21.252	36.682
		Kooliner	25.346*	2.681	.000	17.631	33.061
	Ufi Gel hard	Intact	-70.737*	2.681	.000	-78.452	-63.022
		UNIFAST Trad	-15.567*	2.681	.000	-23.282	-7.852
		Tokuyama Rebase II	13.400*	2.681	.000	5.685	21.115
		Kooliner	9.779*	2.681	.004	2.064	17.494
	Tokuyama Rebase II	Intact	-84.137*	2.681	.000	-91.852	-76.422
		UNIFAST Trad	-28.967*	2.681	.000	-36.682	-21.252
		Ufi Gel hard	-13.400*	2.681	.000	-21.115	-5.685
		Kooliner	-3.621	2.681	1.000	-11.336	4.094
	Kooliner	Intact	-80.516*	2.681	.000	-88.231	-72.801
		UNIFAST Trad	-25.346*	2.681	.000	-33.061	-17.631
		Ufi Gel hard	-9.779*	2.681	.004	-17.494	-2.064
		Tokuyama Rebase II	3.621	2.681	1.000	-4.094	11.336
Thermocycling	Intact	UNIFAST Trad	65.654*	2.681	.000	57.939	73.369
		Ufi Gel hard	72.806*	2.681	.000	65.091	80.521
		Tokuyama Rebase II	83.057*	2.681	.000	75.342	90.772
		Kooliner	83.101*	2.681	.000	75.386	90.816
	UNIFAST Trad	Intact	-65.654*	2.681	.000	-73.369	-57.939
		Ufi Gel hard	7.152	2.681	.091	-.563	14.867
		Tokuyama Rebase II	17.403*	2.681	.000	9.688	25.118
		Kooliner	17.447*	2.681	.000	9.732	25.162
	Ufi Gel hard	Intact	-72.806*	2.681	.000	-80.521	-65.091
		UNIFAST Trad	-7.152	2.681	.091	-14.867	.563
		Tokuyama Rebase II	10.251*	2.681	.002	2.536	17.966
		Kooliner	10.295*	2.681	.002	2.580	18.010
	Tokuyama Rebase II	Intact	-83.057*	2.681	.000	-90.772	-75.342
		UNIFAST Trad	-17.403*	2.681	.000	-25.118	-9.688
		Ufi Gel hard	-10.251*	2.681	.002	-17.966	-2.536
		Kooliner	.044	2.681	1.000	-7.671	7.759
	Kooliner	Intact	-83.101*	2.681	.000	-90.816	-75.386
		UNIFAST Trad	-17.447*	2.681	.000	-25.162	-9.732
		Ufi Gel hard	-10.295*	2.681	.002	-18.010	-2.580
		Tokuyama Rebase II	-.044	2.681	1.000	-7.759	7.671

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Pairwise Comparisons

Dependent Variable: Flexural strength

Repairing material	(I) Thermocycling	(J) Thermocycling	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
						Lower Bound	Upper Bound
Intact	Non thermocycling	Thermocycling	-.936	2.681	.728	-6.262	4.390
	Thermocycling	Non thermocycling	.936	2.681	.728	-4.390	6.262
UNIFAST Trad	Non thermocycling	Thermocycling	9.548*	2.681	.001	4.222	14.874
	Thermocycling	Non thermocycling	-9.548*	2.681	.001	-14.874	-4.222
Ufi Gel hard	Non thermocycling	Thermocycling	1.133	2.681	.674	-4.193	6.459
	Thermocycling	Non thermocycling	-1.133	2.681	.674	-6.459	4.193
Tokuyama Rebase II	Non thermocycling	Thermocycling	-2.016	2.681	.454	-7.342	3.310
	Thermocycling	Non thermocycling	2.016	2.681	.454	-3.310	7.342
Kooliner	Non thermocycling	Thermocycling	1.649	2.681	.540	-3.677	6.975
	Thermocycling	Non thermocycling	-1.649	2.681	.540	-6.975	3.677

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Multiple Comparisons Dependent Variable

Multiple Comparisons

Dependent Variable: Flexural strength
Bonferroni

(I) Repairing material	(J) Repairing material	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intact	UNIFAST Trad	60.4120*	1.89562	.000	54.9566	65.8674
	Ufi Gel hard	71.7715*	1.89562	.000	66.3161	77.2269
	Tokuyama Rebase II	83.5970*	1.89562	.000	78.1416	89.0524
	Kooliner	81.8085*	1.89562	.000	76.3531	87.2639
UNIFAST Trad	Intact	-60.4120*	1.89562	.000	-65.8674	-54.9566
	Ufi Gel hard	11.3595*	1.89562	.000	5.9041	16.8149
	Tokuyama Rebase II	23.1850*	1.89562	.000	17.7296	28.6404
	Kooliner	21.3965*	1.89562	.000	15.9411	26.8519
Ufi Gel hard	Intact	-71.7715*	1.89562	.000	-77.2269	-66.3161
	UNIFAST Trad	-11.3595*	1.89562	.000	-16.8149	-5.9041
	Tokuyama Rebase II	11.8255*	1.89562	.000	6.3701	17.2809
	Kooliner	10.0370*	1.89562	.000	4.5816	15.4924
Tokuyama Rebase II	Intact	-83.5970*	1.89562	.000	-89.0524	-78.1416
	UNIFAST Trad	-23.1850*	1.89562	.000	-28.6404	-17.7296
	Ufi Gel hard	-11.8255*	1.89562	.000	-17.2809	-6.3701
	Kooliner	-1.7885	1.89562	1.000	-7.2439	3.6669
Kooliner	Intact	-81.8085*	1.89562	.000	-87.2639	-76.3531
	UNIFAST Trad	-21.3965*	1.89562	.000	-26.8519	-15.9411
	Ufi Gel hard	-10.0370*	1.89562	.000	-15.4924	-4.5816
	Tokuyama Rebase II	1.7885	1.89562	1.000	-3.6669	7.2439

Based on observed means.
The error term is Mean Square(Error) = 35.934.

*. The mean difference is significant at the .05 level.

Tensile Bond strength test

Descriptive ststistic

Descriptive Statistics

Dependent Variable: Tensile bond strength

Repairing material	Thermocycling	Mean	Std. Deviation	N
UNIFAST Trad	Non thermocycling	22.8460	5.05028	10
	Thermocycling	18.7630	4.84670	10
	Total	20.8045	5.25315	20
Ufi Gel hard	Non thermocycling	21.3830	6.88315	10
	Thermocycling	15.3910	4.67059	10
	Total	18.3870	6.49797	20
Tokuyama Rebase II	Non thermocycling	5.7570	1.59487	10
	Thermocycling	7.7320	1.41665	10
	Total	6.7445	1.78381	20
Kooliner	Non thermocycling	11.1250	2.75602	10
	Thermocycling	9.5400	2.17501	10
	Total	10.3325	2.54949	20
Total	Non thermocycling	15.2777	8.43014	40
	Thermocycling	12.8565	5.67062	40
	Total	14.0671	7.24172	80

Test of normality

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Tensile bond strength	.138	80	.001	.927	80	.000

a. Lilliefors Significance Correction

Levene's Test of Equality of Error Variances

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

Dependent Variable: Tensile bond strength

F	df1	df2	Sig.
6.113	7	72	.000

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

a. Design: Intercept + Material + Thermo + Material * Thermo

Tests of Between-Subjects Effects

Tests of Between-Subjects Effects

Dependent Variable: Tensile bond strength

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2927.375[a]	7	418.196	24.770	.000
Intercept	15830.720	1	15830.720	937.667	.000
Material	2632.436	3	877.479	51.974	.000
Thermo	117.249	1	117.249	6.945	.010
Material * Thermo	177.690	3	59.230	3.508	.020
Error	1215.583	72	16.883		
Total	19973.679	80			
Corrected Total	4142.958	79			

a. R Squared = .707 (Adjusted R Squared = .678)

Pairwise Comparisons Dependent Variable

Repair materials

Pairwise Comparisons

Dependent Variable: Tensile bond strength

(I) Repairing material	(J) Repairing material	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
UNIFAST Trad	Ufi Gel hard	2.417	1.299	.401	-1.108	5.943
	Tokuyama Rebase II	14.060*	1.299	.000	10.535	17.585
	Kooliner	10.472*	1.299	.000	6.947	13.997
Ufi Gel hard	UNIFAST Trad	-2.417	1.299	.401	-5.943	1.108
	Tokuyama Rebase II	11.642*	1.299	.000	8.117	15.168
	Kooliner	8.054*	1.299	.000	4.529	11.580
Tokuyama Rebase II	UNIFAST Trad	-14.060*	1.299	.000	-17.585	-10.535
	Ufi Gel hard	-11.642*	1.299	.000	-15.168	-8.117
	Kooliner	-3.588*	1.299	.044	-7.113	-.063
Kooliner	UNIFAST Trad	-10.472*	1.299	.000	-13.997	-6.947
	Ufi Gel hard	-8.054*	1.299	.000	-11.580	-4.529
	Tokuyama Rebase II	3.588*	1.299	.044	.063	7.113

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Thermocycling condition

Pairwise Comparisons

Dependent Variable: Tensile bond strength

(I) Thermocycling	(J) Thermocycling	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
Non thermocycling	Thermocycling	2.421*	.919	.010	.590	4.253
Thermocycling	Non thermocycling	-2.421*	.919	.010	-4.253	-.590

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Repair materials * Thermocycling condition

Pairwise Comparisons

Dependent Variable: Tensile bond strength

Thermocycling	(I) Repairing material	(J) Repairing material	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
						Lower Bound	Upper Bound
Non thermocycling	UNIFAST Trad	Ufi Gel hard	1.463	1.838	1.000	-3.522	6.448
		Tokuyama Rebase II	17.089*	1.838	.000	12.104	22.074
		Kooliner	11.721*	1.838	.000	6.736	16.706
	Ufi Gel hard	UNIFAST Trad	-1.463	1.838	1.000	-6.448	3.522
		Tokuyama Rebase II	15.626*	1.838	.000	10.641	20.611
		Kooliner	10.258*	1.838	.000	5.273	15.243
	Tokuyama Rebase II	UNIFAST Trad	-17.089*	1.838	.000	-22.074	-12.104
		Ufi Gel hard	-15.626*	1.838	.000	-20.611	-10.641
		Kooliner	-5.368*	1.838	.028	-10.353	-.383
	Kooliner	UNIFAST Trad	-11.721*	1.838	.000	-16.706	-6.736
		Ufi Gel hard	-10.258*	1.838	.000	-15.243	-5.273
		Tokuyama Rebase II	5.368*	1.838	.028	.383	10.353
Thermocycling	UNIFAST Trad	Ufi Gel hard	3.372	1.838	.424	-1.613	8.357
		Tokuyama Rebase II	11.031*	1.838	.000	6.046	16.016
		Kooliner	9.223*	1.838	.000	4.238	14.208
	Ufi Gel hard	UNIFAST Trad	-3.372	1.838	.424	-8.357	1.613
		Tokuyama Rebase II	7.659*	1.838	.001	2.674	12.644
		Kooliner	5.851*	1.838	.013	.866	10.836
	Tokuyama Rebase II	UNIFAST Trad	-11.031*	1.838	.000	-16.016	-6.046
		Ufi Gel hard	-7.659*	1.838	.001	-12.644	-2.674
		Kooliner	-1.808	1.838	1.000	-6.793	3.177
	Kooliner	UNIFAST Trad	-9.223*	1.838	.000	-14.208	-4.238
		Ufi Gel hard	-5.851*	1.838	.013	-10.836	-.866
		Tokuyama Rebase II	1.808	1.838	1.000	-3.177	6.793

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Pairwise Comparisons

Dependent Variable: Tensile bond strength

Repairing material	(I) Thermocycling	(J) Thermocycling	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
						Lower Bound	Upper Bound
UNIFAST Trad	Non thermocycling	Thermocycling	4.083*	1.838	.029	.420	7.746
	Thermocycling	Non thermocycling	-4.083*	1.838	.029	-7.746	-.420
Ufi Gel hard	Non thermocycling	Thermocycling	5.992*	1.838	.002	2.329	9.655
	Thermocycling	Non thermocycling	-5.992*	1.838	.002	-9.655	-2.329
Tokuyama Rebase II	Non thermocycling	Thermocycling	-1.975	1.838	.286	-5.638	1.688
	Thermocycling	Non thermocycling	1.975	1.838	.286	-1.688	5.638
Kooliner	Non thermocycling	Thermocycling	1.585	1.838	.391	-2.078	5.248
	Thermocycling	Non thermocycling	-1.585	1.838	.391	-5.248	2.078

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Multiple Comparisons Dependent Variable

Multiple Comparisons

Dependent Variable: Tensile bond strength

Bonferroni

(I) Repairing material	(J) Repairing material	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
UNIFAST Trad	Ufi Gel hard	2.4175	1.29935	.401	-1.1078	5.9428
	Tokuyama Rebase II	14.0600*	1.29935	.000	10.5347	17.5853
	Kooliner	10.4720*	1.29935	.000	6.9467	13.9973
Ufi Gel hard	UNIFAST Trad	-2.4175	1.29935	.401	-5.9428	1.1078
	Tokuyama Rebase II	11.6425*	1.29935	.000	8.1172	15.1678
	Kooliner	8.0545*	1.29935	.000	4.5292	11.5798
Tokuyama Rebase II	UNIFAST Trad	-14.0600*	1.29935	.000	-17.5853	-10.5347
	Ufi Gel hard	-11.6425*	1.29935	.000	-15.1678	-8.1172
	Kooliner	-3.5880*	1.29935	.044	-7.1133	-.0627
Kooliner	UNIFAST Trad	-10.4720*	1.29935	.000	-13.9973	-6.9467
	Ufi Gel hard	-8.0545*	1.29935	.000	-11.5798	-4.5292
	Tokuyama Rebase II	3.5880*	1.29935	.044	.0627	7.1133

Based on observed means.

The error term is Mean Square(Error) = 16.883.

*. The mean difference is significant at the .05 level.

VITA

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