Sorption and solubility of denture base acrylic: a comparative surface treatment study

by

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DECLARATION

I, Rian George Barnard, declare that the contents of this dissertation represent my own unaided work, and that the dissertation has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed:  **Date:** 10/06/2021

ABSTRACT

Background

Heat-cured PMMA is one of the most frequently used materials in the manufacture of removable dentures. Dentures fabricated with heat-cured material are soluble and able to absorb and release substances. These factors all directly affect the longevity and performance of the prosthesis. Due to laboratory circumstances and time constraints, the polishing procedure may be neglected by technicians. Dentures may also be adjusted by dentists during the fitting procedure while the patient is in the chair to ensure the optimum fit and comfort of the prosthesis. A lack of knowledge, time or equipment may result in the altered surface not being re-polished. Furthermore, dentures may also lose their polished layer as a result of masticatory erosion associated with prolonged use, or because of the actions of patients who alter their prosthesis themselves. These factors increase the surface roughness of the denture and may result in an increase in the sorption and solubility of the denture base material.

Aim

The aim of this study was to compare the sorption and solubility rates of surface-treated, heat-cured acrylic specimens against those of untreated acrylic specimens, soaked in distilled water and artificial saliva.

Methods

Altogether 90 specimens were prepared according to the ISO Standard 20795-1: 2013 (E) to test for sorption and solubility of Type 1, Class 1 denture base material. The specimens underwent a surface treatment procedure in the form of mechanical polishing, or the application of *Optiglaze*™ light-cured varnish and were soaked in grade two distilled water or an artificial saliva solution. The specimens were conditioned to a constant mass, after which the volume of each specimen was calculated. The specimens were soaked for a seven-day period, after which they were reconditioned to a constant mass. The sorption and solubility of the specimens were calculated as recommended by ISO Standard 20795-1: 2013 (E).

Results

The data was analysed using the One- and Two-Way analysis of variance, with the Tukey-Kramer multiple comparison test being used to indicate significant differences among the means of the different sample groups. Mechanical polishing proved to be the most effective surface treatment for reducing solubility, with the specimens recording a mean solubility value of 0.0909 µg/mm^3. The application of *Optiglaze*™ light cure varnish proved to be the most effective surface treatment for reducing sorption, with the specimens recording a mean sorption value of 21,5355 µg/mm^3. The results also indicated that the composition of the medium affects the sorption and solubility of Vertex™ *Rapid Simplified* heat-cured acrylic: the

specimens soaked in the artificial saliva solution recorded lower mean sorption and solubility values than the specimens soaked in distilled water.

Conclusion

The results indicated that both surface treatments, and the composition of the medium in which the specimens were submersed, were successful in reducing either their sorption or solubility levels. The analysis of the results suggests that overall, mechanical polishing was the most effective surface treatment procedure and that artificial saliva was the medium in which the specimens recorded the lowest sorption and solubility values. The results from this study and a review of comparable literature support the suggestion that dentures should be polished by a trained professional at calculated intervals. The application of a light-cured varnish to denture base material may be considered as an alternative to mechanical polishing or used in conjunction to produce optimum results. The submersion of the specimens in an artificial saliva solution imitated the clinical situation of a polished denture in the oral cavity and suggests that the molecular structure of the liquid affects the rate of sorption and solubility of heat-cured denture base material.

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ABBREVIATIONS AND ACRONYMS

Abbreviation/Acronym:

BP	Benzoyl Peroxide
g	Grams
HC	Heat Cure(d)
ISO	International Organisation for Standardisation
LC	Light Cure(d)
m_1	First conditioned mass
m_2	Saturated mass
m_3	Reconditioned mass
mg	Milligrams
MMA	Methyl Methacrylate
PMMA	Polymethyl Methacrylate
Wsl	Water Solubility
Wsp	Water Sorption

GLOSSARY

Acrylic	Polymers of acrylic acid, methacrylic acid, or acrylonitrile, such as acrylic resins used in making dental restorations, prostheses, and appliances *(Miller-Keane Encyclopedia and Dictionary of Medicine, Nursing and Allied Health*, 2003)
Conditioned	Brought or put into a specified state (*Merriam Webster*, 2019)
Denture	Artificial substitute for missing natural teeth and adjacent tissues, including any additions needed for optimum function (International Organisation for Standardisation, 2013:2)
Liquid	Monomeric liquid to be mixed with polymeric particles to form a mouldable dough or fluid resin mixture used for forming denture bases (International Organisation for Standardisation, 2013:2)
Heat-cured	Products requiring application of temperatures above 65 °C to complete polymerisation (International Organisation for Standardisation, 2013:2)
Mass	A quantity or aggregate of matter usually of considerable size (*Merriam Webster*, 2019)
Plasticisation	The process of changing the structure of a polymer to make it easier to bend (*Collins English Dictionary*, 2019)
Polishing	Creation of a smooth and glossy finish on a surface, as of a tooth or denture (*Miller-Keane Encyclopedia and Dictionary of Medicine, Nursing and Allied Health*, 2003)
Powder	Polymeric particles to be mixed with monomeric liquid to form a mouldable dough or fluid resin mixture used for forming denture bases (International Organisation for Standardisation, 2013:2)
Processing	Procedure of preparing a solid denture base polymer plate and/or sample by polymerisation or injection moulding (International Organisation for Standardisation, 2013:3)

Solubility	The maximum quantity of a substance that may be dissolved in another (Helmenstine, 2019)
Sorption	The process or state of being sorbed – absorption or adsorption (*Miller-Keane Encyclopedia and Dictionary of Medicine, Nursing and Allied Health*, 2003)
Surface Treatment	Process designed to alter the surface of a material to achieve a desired property such as hardness or corrosion resistance (IADC, 2016)

Chapter 1

INTRODUCTION

1.1 Introduction

This chapter provides a general overview of the study. It discusses poly-methyl-methacrylate acrylic (PMMA) resin as a denture base material and explores the negative effect of sorption and solubility on the properties of heat-cured denture base material. The factors that influence the extent of sorption and solubility in denture base materials are discussed, as well as the possibility that surface treatments of heat-cured denture base material may inhibit this phenomenon. The relevance and aim of the study are elaborated on and its objectives are clarified. The methodology is briefly explained together with all data-analysis procedures. The chapter concludes with an outline of the structure of the dissertation.

1.2 Background to the study

Heat-cured PMMA is one of the most widely-used materials used for the manufacturing of removable dentures. Over the years, PMMA has been modified and developed to improve its physical and mechanical properties and to facilitate its ease of use in the laboratory (Palaskar et al., 2013:147). PMMA acrylic remains the denture base material of choice for many due to its excellent aesthetics, ease of processing and repair, and relative affordability (Nandal et al., 2013:136). But although PMMA exhibits several properties of an ideal denture base material, drawbacks such as residual monomer toxicity (Rashid et al., 2015: 614), a high coefficient of thermal expansion, poor mechanical strength and dimensional instability (Nandal et al., 2013: 147) have drawn criticism. One of the main contributing factors to PMMA acrylic's limitations is the resin's ability to absorb water when subjected to a moist environment, which causes dimensional instability (Anusavice et al., 2012:489). This dimensional change is an alternating event: Saini et al. (2016:288) explain that if the prosthesis is left in an open and dry environment, it allows water to leave its structure and undergoes contraction (Woelfel et al., 1963:499–504; Dixon et al., 1991:510–513). This dimensional instability nevertheless causes internal stresses to build up within the material, which may lead to fracture of the denture base in the long run (Saini et al., 2016:288; Tuna et al., 2008: 91).

The sorption and solubility of denture base materials do not only affect the material's mechanical properties. The release of unreacted monomer and other water-soluble by-products from the denture base material during function may result in an allergic reaction of the oral mucosa (Tuna et al., 2008:192). Because of this, the water sorption and solubility of denture base materials should be as low as possible.

Surface treatments are one of the final stages in the fabrication of a removable denture. Surface treatments are applied to improve the properties and characteristics of the material, for physical, mechanical, chemical or aesthetic purposes (Al-Rifaiy, 2010:13; Ulusoy et al., 1986:107–112). A review of the literature also suggests that surface treatments may reduce the sorption and solubility of denture base materials. Because sorption and solubility critically affect the clinical and mechanical performance of denture base materials, it was decided to study how different surface treatments applied to heat-cured PMMA affect the material's sorption and solubility. The aim of this study was therefore to compare the sorption and solubility rates of surface treated, heat-cured acrylic specimens with those of untreated acrylic specimens, soaked in distilled water and artificial saliva.

1.3 Problem statement

Dentures fabricated with heat-cured material are of a soluble nature, allowing them to absorb and release substances. These factors all directly affect the longevity and performance of the prosthesis. Due to circumstances including the pressure of deadlines, the surface treatment procedure may be neglected by laboratories to deliver the prosthesis on time. Dentures may also be adjusted by dentists during the fitting procedure while the patient is in the chair to ensure the optimum fit and comfort of the prosthesis. A lack of knowledge, time or equipment may result in the altered surface not being re-treated. Furthermore, dentures may also lose their polished layer as a result of masticatory erosion associated with prolonged use, or because of the actions of patients who alter their prosthesis themselves. These factors increase the surface roughness of the denture and may result in an increase in the sorption and solubility of the denture base.

A review of the literature has established that there are very few published studies investigating the effects that the application of a light-cured varnish to heat-cured PMMA denture base material have on the material's sorption and solubility characteristics. Although there are studies that have reported the effect of mechanical polishing on the sorption and solubility of heat-cure PMMA, establishing a standard has proved to be challenging on account of inconsistencies across the board, as very few documented studies have precisely followed ISO regulations. Studies using surface-treated, heat-cured PMMA specimens submersed in both distilled water and artificial saliva, which could replicate the effect of surface treatments on the sorption and solubility of the material in the oral cavity, are also lacking. Because of the dearth of detailed scientific studies on this topic, it was decided to investigate how surface

treatments, in the form of mechanical polishing and the application of a light-cured varnish to heat-cured acrylic, might affect the sorption and solubility of PMMA material.

1.4 Aim of the study

The aim of this study was to compare the sorption and solubility rates of surface-treated, heat-cured acrylic specimens with those of untreated acrylic specimens, soaked in distilled water and artificial saliva.

1.5 Objectives

To achieve the overall aim of the study, the following objectives were developed:

1. To determine the sorption and solubility of heat-cured acrylic with no surface treatment soaked in distilled water.
2. To determine the sorption and solubility of heat-cured acrylic with no surface treatment soaked in artificial saliva.
3. To determine the sorption and solubility of mechanically polished heat-cured acrylic soaked in distilled water.
4. To determine the sorption and solubility of mechanically polished heat-cured acrylic soaked in artificial saliva.
5. To determine the sorption and solubility of heat-cured acrylic treated with a light-cured varnish soaked in distilled water.
6. To determine the sorption and solubility of heat-cured acrylic treated with a light-cured varnish soaked in artificial saliva.
7. To determine which surface treatment results in the least sorption and solubility of the material.
8. To determine which medium results in the least sorption and solubility of the material.

1.6 Research hypotheses

The study investigated seven hypotheses relating to the sorption and solubility of heat-cured denture base material in respect of the following variables: surface treatment in the form of mechanical polishing or the application of a light-cured varnish and sorption, and solubility of the specimens submersed in either distilled water or artificial saliva. Details of the hypotheses are provided in Chapter Three, Section 3.4 of this dissertation.

1.7 Study design and methods

1.7.1 Study design

An experimental study design was utilised for this research. Experimental studies seek to understand and predict phenomena by investigating the relationships among different relevant variables. During an experimental study, one variable is manipulated while the rest are controlled to see whether the manipulation has any effect (Blakstad, 2008). In this study, seven hypotheses were formulated and tested through the manipulation of variables.

1.7.2 Overview of methods

A total of 90 specimens were prepared according to the ISO Standard 20795-1: 2013 (E) to test for sorption and solubility of a Type One, Class One denture base material. The specimens underwent a surface treatment procedure in the form of mechanical polishing, or the application of a light-cured varnish, after which they were placed on a drying rack. The drying rack was put into a desiccator containing freshly dried silica gel, which was stored in an incubator for 23 (± 1) hours at 37 (± 1) °C. Once the time had elapsed, the specimens were removed from the desiccator and placed in a second desiccator containing freshly dried silica gel for 60 (± 10) minutes at 23 (± 2) °C. This drying procedure was termed the conditioning process. Upon completion of the conditioning process, the mass of each specimen was recorded as per weighing procedure. The conditioning process was continued until all the specimens reached a conditioned mass, after which the volume of each specimen was calculated. The racks containing the specimens were then submerged in a glass bowl filled with either grade two distilled water or an artificial saliva solution. The bowl was sealed with plastic wrap and placed in an incubator kept at a constant of 37 (± 1) °C for seven days (± 2 hours). After the time had elapsed, the specimens were individually removed, dried and weighed. The specimens were reconditioned for a final time until a constant mass was reached. Using the recorded variables and formulae provided by ISO 20795-1: 2013 (E), the water sorption and solubility values of the specimens were calculated. This process is described in greater detail in Chapter Three.

1.7.3 Data analysis

The recorded data was used to calculate the sorption and solubility of the specimens using the formulae provided by ISO Standard 20795-1:2013 (E). The results were tabulated to indicate the sorption and solubility of the surface-treated specimens and those submerged in artificial saliva against the control group. Descriptive statistics were used to summarise the recorded data by means of central tendency (mean and median) and measures of variability (standard

deviation, standard error, range and the minimum and maximum variables). Inferential statistics were then used to determine the associations or relationships between the sorption and solubility of the surface-treated specimens and those submerged in artificial saliva against the control group. The data was analysed using the One- and Two-Way analysis of variance, with the Tukey-Kramer multiple comparison test being employed to indicate significant differences among the means of the different sample groups.

1.7.4 Ethical considerations

This study did not involve any human or animal participants. However, ethical approval was still sought from and granted by the Research Ethics Committee of the Faculty of Health and Wellness Sciences on 4 November 2019 (Approval Reference No: CPUT/HW-REC 2019/H13) (see Appendix A).

1.8 Significance of the study

The sorption and solubility of heat-cured PMMA negatively affect various properties of the material such as, among others, its strength, dimensional stability and biocompatibility. These factors all directly affect the longevity, performance, and comfort of the prosthesis. Many patients do not have the financial reserves to replace such a prosthesis because of mechanical or clinical failure, which could result in the regression of the oral cavity. This has detrimental effects on the patient's self-esteem, social relations, oral health, and general well-being, which may together with other socio-economic factors result in ongoing negative consequences. The study aimed to determine whether certain surface treatment procedures could reduce the amounts of sorption and solubility that occur in heat-cured denture base material. The effectiveness of these treatments was investigated, as well as the possibility that the rate of sorption and solubility of PMMA denture base material may be affected by the molecular structure of the medium in which it is immersed (distilled water or artificial saliva). It was of crucial importance for this study to produce standardised results that might be used as a benchmark for future research. This was done by strictly adhering to all ISO requirements.

The results of this research support the contention that dentures should be polished by a trained professional at calculated intervals. The application of a light-cured varnish to denture base material may be considered an alternative to mechanical polishing or may be used in conjunction with it to produce optimum results. The submersion of the specimens in an artificial saliva solution imitated the clinical situation of a polished denture in the oral cavity and indicated that the molecular structure of the liquid in which the material is submersed affects

the rate of sorption and solubility experienced. The results suggest that dentures fabricated with PMMA denture base material should rather be soaked in distilled water after fabrication and overnight, as opposed to an artificial saliva solution. Such a practice may improve the oral health of the patient as well as increase the longevity of the prosthesis. These two factors play a major role in the well-being of a patient and are therefore of the utmost importance. The conclusions drawn from this study may be used to educate users of heat-cured PMMA denture base material, be they dentists, dental technologists or patients, regarding the clinical importance of a “polished” denture, and the effect the molecular structure of a storage medium may have on the sorption and solubility properties of the prosthesis.

1.10 Arrangement of the dissertation

Chapter 1: provides an introduction to the study. It sketches the background to the research undertaken and articulates the main issues under consideration through the problem statement. The aim and objectives of the study are identified, and an overview of the hypotheses is provided. This is followed by a brief account of the chosen study design, the research methodology and the statistical analyses conducted. The chapter concludes by noting the ethical approval received and adumbrating the significance of the study.

Chapter 2: offers a review of the literature relevant to the study and the problem that it seeks to investigate. It explains the need for dental prostheses and gives an account of the history and development of denture base materials, focusing on heat-activated PMMA as a modern denture base material. The phenomena of sorption and solubility are discussed, together with the detrimental effects they can have on PMMA denture base material. The chapter concludes with the methodology used to measure the rate of sorption and solubility that occurs in denture base materials.

Chapter 3: deals with the methodology of the study. The aim and objectives of the study are presented, and its hypotheses are comprehensively detailed. The choice of study design is explained and the sample size of the study is justified. To ensure that the study complies with the International Organisation for Standardisation criteria (ISO), the criteria for inclusion and exclusion are defined. This is followed by a detailed description of the research methodology. The forms of data analysis and management protocols are described, together with measures taken to ensure the reliability and validity of the results. The chapter ends with a note on ethical considerations pertaining to the study.

Chapter 4: presents the results obtained from the various tests. The data is summarised by means of descriptive statistics and the objectives are reviewed to accept, reject or partially accept the hypotheses. Inferential statistics are provided in the form of One- and Two-Way Analysis of Variance and possible associations between variables are considered. Significant

differences among the means of the different sample groups are identified using the Tukey-Kramer multiple comparison test. The chapter concludes with a summary of the results, highlighting the findings that are crucial to the aim of this study.

Chapter 5: discusses the results of the study. The results presented in Chapter Four are analysed in depth alongside the pertinent research objectives and hypotheses, in sequential order. Associations between the results of this study and of others in the same field are identified, and the findings are appraised together with possible explanations for them.

Chapter 6: draws conclusions from the relevant results and discussion. An overview of the study is provided, its significance is indicated, and its limitations are summarised. The study's contribution to its field of research is highlighted, together with recommendations for possible future research. A few concluding remarks serve to round off the chapter.

1.11 Conclusion

This chapter has reflected on the role of poly-methyl-methacrylate acrylic resin in the profession of dental technology, highlighting both its advantages and shortcomings. As dentures are the primary choice of prosthesis for the elderly and individuals from lower socio-economic populations, the longevity of the prosthesis is of the utmost importance as financial reserves are not always available for the patient to replace prostheses if they fail. Because of this, methods to reduce and control the amount of sorption and solubility experienced by heat-cured PMMA were investigated. The problem was fully described and the overall aim and objectives of the study established. This was followed by a summary review of relevant literature, and a brief account of the study's design and research methodology. As mentioned above, Chapter Two will offer a comprehensive review of the scientific literature in this field of research.

Chapter 2
LITERATURE REVIEW

2.1 Introduction

The literature review presented in this chapter covers both the history and contemporary relevance of dental prostheses and denture base materials, to provide a broad overview of the topic and to contextualise the research objectives. Heat-activated PMMA is discussed as a denture base material and its chemical nature is explained to account for why the material reacts to certain stimuli in the way that it does. Sorption and solubility are identified as two major drawbacks of denture base materials and their detrimental effects are thoroughly documented. The review explores relevant variables, indicating that mixing ratios, polymerisation cycles and the thickness of the denture base are external factors that may influence the material's sorption and solubility. It also furnishes evidence that surface treatments and the submersion of denture base material in an artificial saliva solution may be successful methods for achieving the objectives. The chapter concludes with a review of the methodology used to test for the sorption and solubility of denture base material.

2.2 Dental prostheses

Tooth loss is one of the major consequences of oral disease. It is regarded as a major public health concern and affects nearly 3.5 billion people worldwide (James et al., 2018:1795; WHO, 2020). Tooth loss may be the result of various conditions such as periodontal disease, caries, oral cancers, trauma, infection, failed endodontic treatments, oral manifestations due to HIV infection and noma. Poor oral health and personal habits such as smoking, alcohol abuse and high sugar intake may initiate and aggravate these conditions. Oral disease, if not treated, may have various consequences, not only for the individual's physical health such as pain, discomfort, impairment and disfigurement, but may also affect the individual socially, psychologically and emotionally (WHO, 2020; Dosumu et al., 2014:43). Artificial appliances known as dental prostheses may be worn to alleviate these effects. According to Zwemer (1982:236): "A dental prosthesis is an artificial replacement for one or more natural teeth, part of a tooth or associated oral structures". It is designed to restore the function, phonetics, and aesthetics of the oral cavity. Various sources suggest that dental prostheses can be tracked back to approximately 600BC when the Etruscans resided in Northern Italy (Elsenpeter, 2018; Gonzalez, 2014:85; Donaldson, 1980:117). The Etruscans are known for being one of the first civilisations to incorporate gold into their dental prostheses.

Replacement teeth were initially carved out of wood, animal teeth or ivory, but if possible, the lost tooth would be cut off above the root and used as the “replacement” tooth. The replacement tooth was fastened to a gold band or wire with rivets and placed or wrapped around the adjacent teeth to secure it in position (Elsenpeter, 2018; Donaldson, 1980:117). In modern dentistry, dental prostheses can be classified as either removable or fixed, and are supported by remaining oral structures, implants or both. Fixed prostheses include crowns, bridges, veneers, inlays and onlays, whereas removable prostheses are constructed in the form of partial or complete dentures (Perry, 2018). Removable dentures, whether full or partial, are still the most prevalent dental prostheses worldwide. In recent times, there has been an increase in the demand for fixed prostheses due to their apparent advantages over removable prostheses, in terms of comfort, aesthetics or preserving underlying alveolar bone. This trend is however not as marked among the lower socio-economic class or individuals in the older age groups due to the costs entailed (Zitzmann et al., 2007:20–33; Radnai et al., 2013:108). In South Africa, the Department of Health in the Western Cape reported having manufactured 4853 dentures for those in need for the 2017–2018 fiscal year. This number exceeded their planned target by 958 dentures (Westerncape.gov.za, 2018:82).

2.3 History of denture base materials

Denture base materials as known today did not develop until the 1700s. In 1728, Pierre Fauchard published the *Le chirurgien dentiste,* which dealt with the description and construction of full and partial artificial dentures (Anusavice et al., 2012:7). Fauchard suggested that dentures should rather be made from porcelain, instead of an ivory insert with cadaver teeth, as the result would be more aesthetically pleasing and hygienic. The high firing shrinkage of porcelain initially created many problems and the first recorded porcelain denture was fabricated in 1744 by a man named Duchateau. In 1850, denture base material was revolutionised when Charles Goodyear introduced and patented the vulcanisation process. This resulted in a hardened rubber being used as denture base material, as it was cheap and easy to produce, provided an accurate fit, and porcelain teeth could be attached to it (Van Noort, 2013:xii). Unfortunately, vulcanite lacked the visual appeal required for an ideal denture base. The search for more aesthetic denture bases led to the introduction of a celluloid denture base in 1870. Celluloid displayed the required translucency but lacked longevity as it distorted and turned black and green after prolonged use. To resolve this problem, camphor was added as a plasticizer, but this gave the material an unpleasant taste and odour (Mittal et al., 2009:66). The foundation of modern denture bases was laid in the 1930s when Dr Walter Bauer introduced PMMA as a replacement for vulcanite. PMMA is a clear and colourless polymer of methyl methacrylate, with the chemical formula $(C_5H_8O_2)n$ (Alla et al., 2015:82).

The material's transparency, stability in the oral cavity, ease of repair and processing, UV resistance and neutral taste in the mouth are all properties regarded as ideal for a denture base (Fischer, 2012). PMMA has been researched, modified and developed over the years in order to improve its mechanical and physical properties and to facilitate its ease of use in the laboratory (Palaskar et al., 2013:147). Various researchers have tabulated what they regard as the requirements for an ideal denture base. These are listed in Table 2.1, below:

Table 2.1: Ideal requirements of denture base materials
(Alla et al., 2015:84; McCabe & Walls, 2008:110–112)

Property	**Requirements**
Biological	• Should be non-toxic, non-irritant and non-carcinogenic.
Chemical	• Should bond with artificial teeth and denture liners. • Should be insoluble and chemically stable in the oral environment.
Aesthetic	• Should exhibit sufficient transparency and translucency to match the appearance of the oral tissues. • Should be capable of being tinted or pigmented. • Should maintain these optical properties throughout the service period of the appliance.
Other	• Should be inexpensive and have an adequate shelf life. • Should be easy to manipulate and repair. • Should be radio opaque. • Low sorption and solubility. • Good thermal conductivity • Should have adequate abrasion resistance. • Low specific gravity.

PMMA denture base materials can be categorised according to the mechanism that initiates their polymerisation. These include heat-, chemical- and light-activated PMMA denture base resins (Anusavice et al., 2012:475–485). They can further be classified according to their processing method, as indicated by ISO Standard 20795-1: 2013 (E) which has categorised PMMA denture base material into the following types, as illustrated in Table 2.2, below:

Table 2.2: PMMA denture base polymers

(International Organisation for Standardisation, 2013)

Type	Material	Class
1	Heat-Polymerisable Polymers	1: Powder and liquid 2: Plastic cake
2	Auto-Polymerisable Polymers	1: Powder and liquid 2: Powder and liquid pour-type resins
3	Thermoplastic Blank or Powder	
4	Light-Activated Materials	
5	Microwave-Cured Materials	

2.4 Heat-activated PMMA

Heat-activated PMMA is used for both the repair and fabrication of various appliances in the field of dental technology. The material's popularity is attributed to its colour, translucency, stability in the oral cavity, ease of processing and repair, and physical properties that are acceptable for dental use (Nandal et al., 2013:136; Anusavice et al., 2012:475). Heat-activated denture base polymers are usually supplied in the form of a powder and liquid and have a composition as illustrated in Table 2.3, below:

Table 2.3: Composition of heat-activated denture base resins

(Bhola et al., 2010:132; Anusavice et al., 2012:475)

Powder	Liquid
• Polymethyl methacrylate	• Methyl methacrylate
• Initiator – Benzoyl peroxide	• Plasticizers – Dibutyl phthalate
• Plasticiser – Dibutyl phthalate	• Inhibitor – Hydroquinone
• Dyes - Mercuric sulphide, Cadmium sulphide, Ferric oxide	• Cross-linking agent – Glycol dimethacrylate
• Opacifiers - Zinc or titanium oxides	
• Inorganic particles – Glass fibres, zirconium silicate, whiskers of alumina, boron nitride and carbon fibres	

The powder (polymer) and liquid (monomer) are mixed according to a ratio recommended by the material's manufacturer. The monomer is absorbed by the polymer beads and results in the mixture forming a dough-like mass. Once the material's dough time has elapsed, it is packed into a mould (Anusavice et al., 2012:479; Fischer, 2012). Heat-activated PMMA denture base material is polymerised by addition polymerisation (O'Brien, 2008:77). Ouellette & Rawn (2014:588) explain that the process of addition polymerisation involves a chain reaction during which one carbon-carbon double bond adds to another. When using heat-activated PMMA, the mould containing the polymer–monomer mixture is heated in a water bath to activate the benzoyl peroxide initiator. The benzoyl peroxide breaks down to produce free radicals (Nisar et al., 2015:716). Anusavice et al. (2012:92) define a free radical as an atom or group of atoms possessing an unpaired electron.

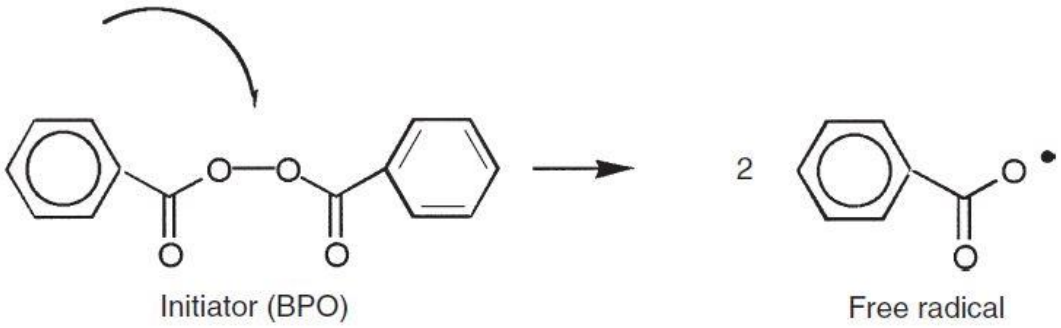

Figure 2.1: Activation of benzoyl peroxide

(Anusavice et al., 2012:101)

The free radical with its unpaired electron acts on the vinyl group of the methyl methacrylate molecule. The double bond of the methyl methacrylate molecule is split, resulting in the free radical forming a single bond with the monomer on one side, while the remaining free electron remains unpaired. This results in a radicalised monomer molecule (Anusavice et al., 2012:101–107; Fischer, 2012; Jambur et al., 2016:45; O'Brien, 2008:77–78).

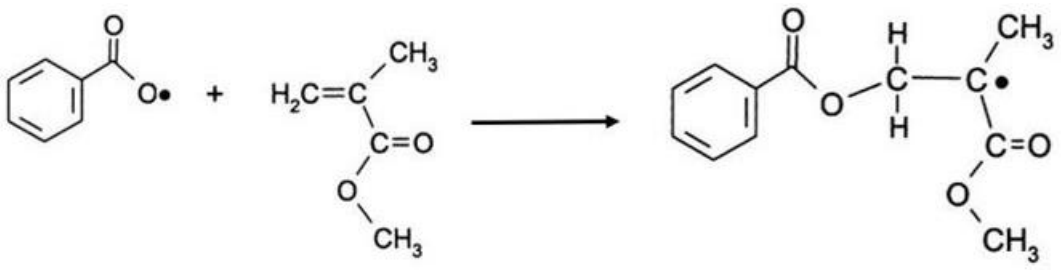

Figure 2.2: Initiation of the methyl methacrylate molecule

(Anusavice et al., 2012:102)

The radicalised monomer interacts with other methyl methacrylate molecules in the network. Its unpaired electron interacts with the double bond of the remaining methyl methacrylate molecules, initiating a chain reaction where the remaining monomer molecules attach to a radicalised monomer chain. This occurs at various sites in the network and results in the formation of many radicalised monomer chains. This process is known as chain growth (Anusavice et al., 2012:101–107; Fischer, 2012; O'Brien, 2008:78).

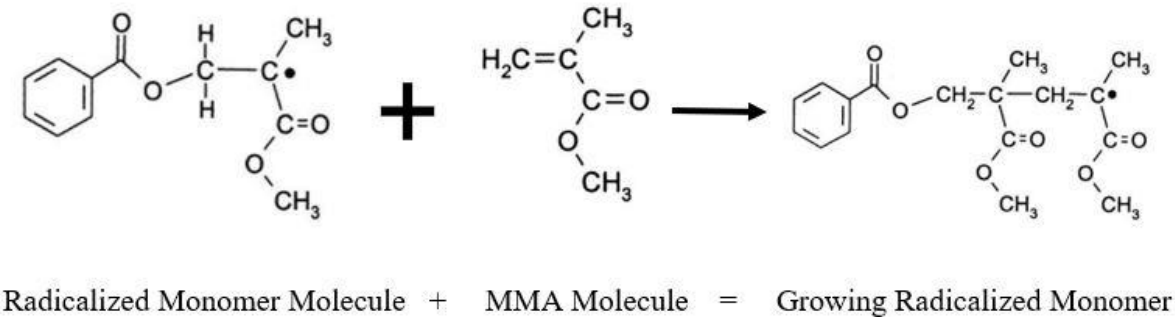

Figure 2.3: Growing radicalised monomer molecule

(Anusavice et al., 2012:103)

Addition polymerisation does not only take place between molecules, but between radical chains as well. Covalent bonds form between the integrating radicalised monomer chains resulting in the formation of large macromolecules. This process continues until the monomer molecules in the network have been exhausted (Anusavice et al., 2012:101–107; Rashid et al., 2015:615).

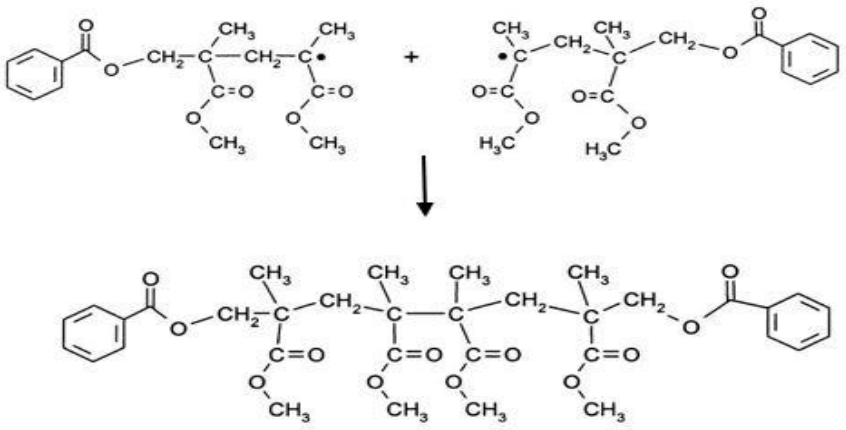

Figure 2.4: Formation and termination of macromolecules through chain transfer (Anusavice et al., 2012:104)

Not all the monomer molecules are polymerised during the polymerisation process, which results in unreacted residual monomer being present in the polymerised material. The unreacted monomer may leach from the denture base during function, resulting in cytotoxic effects in the oral cavity (Rashid et al., 2015:615). Ferracane (2006:211–222) reviewed the literature on the hygroscopic and hydrolytic effects in dental polymer networks, and noted that the structural and chemical characteristics of a polymer's network largely determine the extent of sorption and solubility that will occur within a material when exposed to an aqueous environment. The hydrophilicity of the polymer, differences in the solubility parameter between the polymer and the solvent, the cross-linking density and porosity of the network and the presence of a reinforcing filler, may all significantly influence these phenomena (Ferracane, 2006:213). After decades of research and product development, heat-cured PMMA still has certain drawbacks such as porosity, water sorption and solubility, cytotoxic effects of leaching residual monomer, and poor impact, fatigue and mechanical strength (Rashid et al., 2015:614–619; Sujitha et al., 2018:251–255; Nandal et al., 2013:136–143). This has resulted in the users of PMMA and researchers investigating the effects of external procedures on the properties of denture base materials, such as soaking the denture base in water prior to delivery, and different polymerisation cycles, mixing ratios and surface treatments.

2.5 Sorption

When reviewing denture base materials, sorption is a crucial property to consider. High sorption values may have detrimental effects on the mechanical properties of a denture as well as reduce its longevity. These are both crucial aspects of a successful denture base material. Sakaguchi & Powers (2012:51) explain that sorption is a process of adsorption and absorption. Adsorption is the molecular adhesion of a substance to the surface of a material, whereas

absorption is the diffusion of a substance into the body of the material. When both are taking place, the term sorption is used to classify the phenomenon. Sorption occurs when a denture base is exposed to a moist environment and is initiated by the polarity of the PMMA's molecules. PMMA materials contain carbonyl groups, to which water molecules have an affinity (Figuerôa et al., 2018:6). Water molecules are adsorbed to the surface of the material and are further absorbed into the body of the denture base through porosity and intermolecular spaces via diffusion (Anusavice et al., 2012:489). According to Ferracane (2006:215), the research conducted by Braden et al. (1976:730–732), Kalachandra & Turner (1987:329–338) and Sideridou et al. (2004:367–376) all indicate that water sorption follows Fick's law of diffusion, which is based on the movement of molecules from a high concentration to a low concentration.

The extent and rate of sorption experienced by the material are influenced by the density of the polymer network and the potential for hydrogen bonding and polar interactions to take place (Ferracane, 2006:214). As water diffuses into the molecular structure of the PMMA material, its molecules occupy the intermolecular voids between the polymer chains (Anusavice et al., 2012:489; Figuerôa et al., 2018:6). Due to the weak secondary bonds in PMMA materials, the ingress of water molecules can force the polymer chains apart, resulting in the expansion of the polymerised material (O'Brien, 2008:9). Polymers with a high cross-linking density have illustrated lower sorption values due to the limited free space available to be occupied by water molecules within the structure of the network (Ferracane, 2006:214). The sorption of water into the structure of PMMA is an alternating event. When the material is exposed to an open and dry environment, it allows water to leave its structure and the material undergoes contraction (Saini et al., 2016:288). This ongoing dimensional change and the instability caused by continuous expansion and contraction creates internal stresses within the material, which may result in the crazing and fracture of the denture (Tuna et al., 2008:191).

Surface cracks may develop as a result of dimensional instability that can form points of entry or attachment for various bacteria, yeasts and moulds (Spasojević et al., 2012:1272). The interaction of water molecules with the polymer chains of PMMA may also result in the plasticisation of the denture base, affecting the mechanical properties of the material by decreasing its hardness, fatigue limit and transverse strength (Tuna et al., 2008:192; Miettinen et al., 1996:531).

The continuing search for methods of reducing the levels of sorption experienced by denture base materials led Arima et al. (1996:476–480) to investigate the effect of six different cross-linking agents on the water sorption and solubility of self-cured denture base resin. It was found

that the chemical nature of the polymer in comparison to that of the water molecule directly affected the water sorption of the denture base material: the solubility of the material decreased as the presence of cross-linking agents increased in concentration. The study also observed an increase in sorption levels when cross-linking agents that contained hydrophilic linkages were increased in concentration. This result indicates that the chemical nature of the cross-linking agent may have a greater effect on the sorption and solubility of a material than a higher molecular density. Saini et al. (2016:288) investigated the sorption and solubility of heat-cured and self-cured acrylic resins immersed in different solutions. The solutions included distilled water, artificial saliva, denture cleansing solution, a mixture of distilled water and denture cleansing solution, and a mixture of artificial saliva and denture cleansing solution. The mean water sorption values varied from 17.5 ± 0.88 to 27.25 ± 1.04 μg/mm^3 for heat cured and from 12.75 ± 0.55 to 19.75 ± 1.04 μg/mm^3 for self-cured, making these values statistically significant. On the other hand, the water solubility mean values were not statistically significant as they varied from 0.25 ± 0.55 to 1.5 ± 0.55 μg/mm^3 for heat cured and from 1.5 ± 0.55 to 6.5 ± 0.55 μg/mm^3 for self-cured (Saini et al., 2016:288). The study indicated that the sorption rate of heat-activated PMMA denture base material was the least when it was stored in an artificial saliva solution, rather than distilled water or a denture cleansing solution. It can therefore be speculated that the rate sorption of PMMA denture base material may also be affected by the molecular structure of the solution in which it is immersed. According to ISO standards 20795-1:2013(E), the water sorption of heat-cured acrylic should not exceed 32 μg/mm^3.

2.6 Solubility

The solubility of denture base materials directly impacts the biocompatibility of the prosthesis, as high levels of diffusion may increase the risk of various cytotoxic effects. The importance of reducing the levels of solubility in a prosthesis cannot be stressed enough. According to Helmenstine (2019), “[s]olubility is defined as the maximum quantity of a substance that can be dissolved in another”. PMMA denture base material should be insoluble with a molecular network of high chemical and thermal stability (Ferracane, 2006:211). Anusavice et al. (2012:489) claim that PMMA denture base resins are insoluble in water, as well as in most substances that may be found in the oral cavity.

Both Ferracane (2006:211–222) and Tuna et al. (2008:197) explain that even though PMMA denture base materials are insoluble in the oral environment, they contain by-products such as unreacted monomer, plasticisers and other water-soluble additives that can absorb water and chemicals from the environment and release them into the oral cavity. The literature suggests that unreacted residual monomer is one of the primary soluble substances released

from PMMA denture base material during function (De Andrade Lima Chaves et al., 2012:115). The solubility of such materials needs to be as low as possible to prevent the patient from experiencing cytotoxic effects such as erythema, oedema and urticaria (Koutis & Freeman, 2001:203–206). Both the uptake and release of substances from denture base material occur as a result of diffusion. Klazema (2020) describes diffusion as a process where substances such as water molecules and ions enter and leave the molecular structure of materials. This movement is enabled by a concentration gradient, resulting in molecules moving from an area of high concentration to an area of low concentration. This process is said to continue until the solute is evenly dispersed between the two materials. The process is governed by the diffusion coefficient of the medium. The diffusion coefficient is a value indicating the rate at which diffusion can take place and is influenced by the temperature and viscosity of the medium (Dickson, 2020).

Kedjarune et al. (1999: 25–30) investigated the release of methyl methacrylate from heat-cured and auto-polymerised denture base material and concluded that the amount of residual monomer present after polymerisation is influenced by both the polymerisation method and the liquid powder ratio of the material. The findings of this study were in line with those of Kostić et al. (2020:254–263), who investigated the residual monomer content present in dental acrylic polymers and its effect after tissue implantation. The residual monomer content present in cold polymerised PMMA (15.75mgMMA/g PMMA) was higher than that of heat polymerised PMMA (10.96mgMMA/gPMMA), with cold polymerised material also showing a greater inflammatory response of soft tissue. The materials used in this study were Triplex Cold and *Ivoclar Vivadent*™ (hot), with a liquid-to-powder ratio of 10ml:13g and 10ml:23.4g, respectively.

Tuna et al. (2008: 191–197) investigated the sorption and solubility of various acrylic resins including both heat- and self-cured materials. The results indicated that heat-cured acrylic resins had lower solubility values than most of the self-cured acrylic resins. As the primary difference between heat- and self-cured materials is the liquid-to-powder ratio, and taking the study by Kostić et al. (2020: 254–263) into account, it can be concluded that the amount of unreacted monomer present in the material after polymerisation directly affects the degree of solubility expressed by the material. As the amount of residual monomer present in the denture base after processing affects the rate of solubility of the material, it should always be kept as low as possible. It is therefore advisable always to follow the manufacturer's recommendations stringently regarding the use of the material to ensure optimum results. Various techniques and methods to reduce the solubility of denture base material after polymerisation have been investigated, and many have proven to be effective, but they are not always practically executable. A review of the literature indicates that both extended polymerisation cycles (Wang

et al., 2018) and soaking the material for at least 24 hours in distilled water (Bayraktar et al., 2006:340–345) before delivery may reduce the solubility of the denture base material. However, as time is one of the major constraints in a commercial laboratory, such methods are not always possible to execute. For denture base polymers, the loss in mass (soluble matter) should not exceed 1.6 µg/mm^3 for types 1, 3 and 5 polymers and should not exceed 8.0 µg/mm^3 for type 2 polymers (International Organisation for Standardisation, 2013).

2.7 Mixing ratios

Manufacturers of PMMA denture base material all recommend different powder/liquid mixing ratios for their respective products. To achieve optimum results, Vertex™ recommends 2.3 grams of powder for every millilitre of monomer used for their Vertex™ *Rapid Simplified* heat-cured acrylic. However, the modification of these mixing ratios by dental laboratory technicians attempting to manipulate the handling properties of the material is not uncommon. Additional monomer can be added to the mixture to extend the working time of the material, but a higher monomer concentration can lead to a greater amount of residual monomer present in the material after polymerisation. The addition of extra monomer is an issue of concern as it may increase the chances of patients experiencing various cytotoxic effects from the denture base material during use (Kedjarune et al., 1999:25–30). This is in line with the findings of Kostić et al. (2020: 254–263) and Tuna et al. (2008:191197), who reported that the liquid/powder ratio of the material affects both the residual monomer present after polymerisation as well as the rate of solubility of the material. Kostić et al. (2020:254–263) also tested the cytotoxic effects at various levels of residual monomer and concluded that higher levels of residual monomer can be associated with a greater inflammatory response of soft tissue.

2.8 Polymerisation cycle

Anusavice et al. (2012:93) characterise polymerisation as “a chemical reaction in which monomers of a low molecular weight are converted into chains of polymers with a high molecular weight”. The polymerisation of denture base polymers is induced by an initiator which is part of the material’s chemical composition. Initiators react when exposed to external trigger mechanisms such as light or heat, dependent on the material.

Various studies mention that incorrect polymerisation cycles can negatively impact the physical, mechanical, and biological properties of the denture. Each manufacturer recommends a polymerisation cycle that is time and temperature orientated for a specific material. It is of crucial importance strictly to adhere to these recommendations to ensure optimum results. This is confirmed by Nisar et al. (2015:713–718), who investigated the effect of varying powder liquid ratios and different polymerisation cycles on the residual monomer

concentrations of heat-cured denture base resin. The results indicated that both the liquid/powder ratios and polymerisation cycles influenced the amount of residual monomer present after polymerisation. Due to the residual monomer concentrations being measured at 24-, 48- and 72-hour intervals, the author could also conclude that the residual monomer concentrations decrease with time. It was observed that the maximum amount of monomer is released within the first 24 hours and it is therefore advised that dentures fabricated with PMMA acrylic are soaked in distilled water for 24–48 hours before insertion.

Altering the polymerisation cycle may lead to insufficient monomer-polymer conversion or over-heating of the monomer, resulting in an increased presence of residual monomer after polymerisation or porosity (Figuerôa et al., 2018:6). The literature indicates that both excess residual monomer and porosity may increase the sorption and solubility experienced by denture base acrylics. Tuna et al. (2008:196) reported that materials with a homogenous structure are less susceptible to sorption and solubility but that high porosity values conduce to the opposite effect. The effect of residual monomer on the sorption and solubility of denture base materials is thoroughly documented in Sections 2.6 and 2.7, above.

2.9 Denture base thickness

A review of the literature indicates that previous studies like those conducted by Engelbrecht (2010), Tuna et al. (2008:191–197) and Saini et al. (2016:288) all deviated from ISO specifications by altering (for various reasons) the thickness, shape, and construction methods of their specimens. A study conducted by Duymuş & Yanikoğlu (2004:8–13) tested the influence of the thickness and processing method of PMMA denture base material on the linear dimensional change and water sorption of the material. The study found that the thickness of the specimens was statistically significant regarding the water sorption of acrylic resin. The water sorption of the 4.5mm specimens was higher than that of the 1.5mm specimens. The thicker specimens also took more time to reach a conditioned mass. Engelbrecht (2010) fabricated specimens by investing 50 x 2mm discs made from Proform™ mouth guard sheets, as opposed to making use of a stainless-steel mould as stipulated by ISO. It was stated that the thickness of the specimens was increased from 0.5mm to 2mm to reduce the risk of fracture during a polishing procedure. The author speculated that it was because of the increase in thickness that some specimens failed to reach a conditioned mass during the conditioning process. The ISO Standard 20795-1: 2013 (E) for testing sorption and solubility requires specimens to have a thickness of 0.5 (± 0.05) mm and a diameter of 50 (± 0.1) mm. Due to the importance of these standards, the researcher will strictly adhere to ISO requirements and specifications in order to produce standardised results that can be used as a benchmark for future research.

2.10 Surface treatment of denture base material

According to the IADC (2016), "[s]urface treatments are processes by which the surface of a material is altered to achieve a desired property, such as hardness or corrosion resistance". When dealing with denture base polymers, surface treatments are applied to improve the properties and characteristics of the material, whether for physical, mechanical, chemical or aesthetic purposes. Surface treatments of PMMA denture base materials include mechanical and chemical polishing, as well as the application of light-cured varnishes. PMMA denture base surfaces that are highly polished and smooth promote increased gingival health, including chewing efficiency, patient comfort, improved aesthetics and prosthesis longevity. Finishing and surface treatment procedures reduce the surface roughness and tension of the material, resulting in reduced bacterial colonisation and plaque accumulation (Sakaguchi & Powers, 2012:49–50; Anusavice et al., 2012:232).

There are two main polishing techniques used in the industry to create a smooth denture surface. Both mechanical and chemical polishing can be used to achieve a satisfactory result. Mechanical polishing is the conventional polishing technique, making use of abrasives of varying degrees to alter the surface of the material by reducing its roughness or texture (Abuzar et al., 2010:578). Mechanical polishing is performed through the application of various rubber abrasives, fine-particle discs, strips, and polishing pastes to achieve desirable results. It is also advised that the application of these materials be both multidirectional and intermittent as surface scratches and debris are orientated in many directions. Intermittent contact also prevents excessive heat generation which may lead to warpage (Anusavice et al., 2012:236). Chemical polishing reduces the overall polishing time and is able to reach areas of the denture that are not accessible to mechanical polishing. When making use of chemical polishing, the prosthesis is placed in a chemical polisher containing heated methyl-methacrylate, after the finishing procedures (Rahal et al., 2004b:225; Braun et al., 2003:91).

Various studies have investigated the efficiency of mechanical and chemical polishing techniques and their effect on the surface roughness of denture base acrylic resins. Authors such as Al-Kheraif (2014:56–62), Al-Rifaiy (2010:13–17) and Rahal et al. (2004b:225–230) all found that mechanical polishing is more effective in reducing the surface roughness of denture base materials than the chemical alternative. They therefore concluded that mechanical polishing is a more effective polishing technique. Jones et al. (2004:42–45) conducted a study to determine the detection threshold value of the surface roughness of restorations by patients using their tongue. The results indicated that 60% of volunteers could successfully distinguish surface roughness values between 0.25 and 0.50µm. This range is in line with that of natural

enamel found in the oral cavity. The study concluded that the surface roughness of restorations should not exceed 50µm if it is not to be detected by patients. A polishing procedure may not only help reduce the surface roughness of denture base polymers but may also have a significant effect on the sorption and solubility levels of the material.

A study conducted by Engelbrecht (2010) investigated the factors influencing the sorption, solubility and cytotoxicity of a heat-cured denture base polymer. One of the factors investigated was the effect of a conventional polishing procedure on the rate of sorption and solubility of a heat-cured denture base polymer. The results indicated that the polishing procedure reduced both the sorption and solubility values of the material, but that this reduction was only statistically significant for solubility. The author speculated that these occurrences could be attributed to the different chemical processes and the polarity and size of different molecules involved in the processes of sorption and solubility. These results were in agreement with Al-Muthaffar (2016:481–488), who aimed to determine the effect of a conventional polishing procedure on the water sorption of cold- and heat-cured acrylic denture base material. Al-Muthaffar (2016:481–488) found that the conventional polishing procedure significantly reduced the amount of sorption experienced by both cold- and heat-cured acrylics. He reasoned that the observed results might have occurred because the heat generated during the conventional polishing procedure often exceeds the glass transition temperature of the acrylic, which could result in the smearing of the resin's surface. Al-Muthaffar (2016:486) notes the smeared surface decreases the polarity of the acrylic by minimising the concentration of polar sites available to form hydrogen bonds with water molecules. Polished surfaces have lower surface roughness than unpolished ones. The irregular surface of the unpolished specimens means that their surface area is greater than that of the polished specimens, resulting in a greater interface area between the specimens and water molecules. This greater contact may lead to greater water uptake (Al-Muthaffar, 2016:486). It can also be explained in terms of the contact angle hysteresis between the water droplets and the surfaces of the specimens. Rahal et al. (2004a:1075–1079) reference Monse´ne´go et al., (1989:308–312), who explained that water droplets form lower contact angles with rougher surfaces. Surfaces that produce lower contact angles are of a more hydrophilic nature and therefore increase the material's affinity to water.

Mechanical and chemical polishing procedures are not the only surface treatments that may improve the characteristics and properties of denture base materials. Companies such as GC America™ and Vertex™ have developed light-cured, gloss varnish products that can be applied to the surface of PMMA denture base material. These products provide a high shining finish to acrylic areas that are hard to polish and reduce the adhesion of plaque or food

residues (GC America, 2020; Vertex Dental, 2019). GC America (2020) claims that "*Optiglaze*™ is a glossy, protective agent with high resistance to wear and discolouration that provides an aesthetic glossy surface on indirect composite restorations, artificial teeth, removable dentures, temporary crowns and individual acrylic trays". Vallittu (1996:188–192) tested the effect that surface treatments of auto-polymerising denture base material would have on the residual monomer content and release from the material. The test specimens were either conventionally polished or treated with a light-cured resin. The results indicated that both surface treatment procedures were effective in reducing the content and release of residual monomer from the material, with the light-cured resin technique proving to be most effective. Even though the specimens used by Vallittu (1996:188–192) were manufactured from an auto-polymerised denture base material, similar results are expected to be observed with the application of these surface treatments to heat-polymerised resins.

These results supported those of Szabó et al., (1985:249–256) who tested the effect of a light-cured resin on the properties of both auto- and heat-polymerised denture acrylic. The results indicated that the application of the light-cured resin may reduce the quantity of soluble components leaking from the material. The coated materials also recorded an increase in hardness, but this effect was thought to be countered by the increase in water sorption observed. As surface sealants in the form of light-cured varnishes have become more popular as a finishing procedure, Biazuz et al. (2015:27–30) decided to investigate the water sorption, solubility and surface roughness of two different surface sealants in the form of *Natural Glaze* (DFL) and *Permaseal* (Ultradent). The results indicated that sorption and solubility values recorded by the specimens sealed with *Natural Glaze* were significantly lower than those of *Permaseal* ($p<0.05$), and that the surface roughness of the respective specimens was not affected by the variation in sorption and solubility values. The authors concluded that the variation in sorption and solubility values were due to the different organic compositions of the two surface sealants.

2.11 Artificial saliva solution

Artificial saliva is a crucial component in the testing of dental materials as it may indicate how these materials behave in the oral environment. Pytko-Polonczyk et al. (2017:807–813) conducted a study of the use of artificial saliva in biological experiments and noted that it was not possible to create a synthetic formula identical to that of natural saliva due to the number of factors influencing its composition. Pytko-Polonczyk et al. (2017:807–813) comprehensively reviewed the published literature in which artificial saliva had been used and found that the only component present in all the variations of artificial saliva was KCl. The pH of artificial

saliva also varied from 5.0 to 7.3, which is similar to its physiological lower and upper limits. Comparing various models of artificial saliva, Pytko-Polonczyk et al. (2017:807–813) determined that for the evaluation of the sorption and solubility of conventional dental composite materials one should use artificial saliva with a pH of 6.75 and the approximate composition illustrated in Table 2.4:

Table 2.4: Artificial saliva composition

(Pytko-Polonczyk et al., 2017:811)

Ingredient	**Quantity (mg/L)**
$C_8H_8O_3$	2000
$C_8H_{15}NaO_8$	10000
KCl	625
$CaCl_2$	166
KH_2PO	326
$MgCl_2$	59
Potassium Hydroxide (KOH) and distilled water can be added to achieve the correct pH.	

Companies such as Pickering Laboratories™ have developed artificial saliva for medical and dental research. According to Pickering Test Solutions (2019), “[o]ur artificial saliva solution is formulated according to literature references from medical and dental research and is only intended for product testing and research, and not for medical use”. Their ready-to-use solution contains sodium carboxymethyl cellulose to increase the viscosity of the solution and mimic the consistency of natural human saliva. The solution can be stored at room temperature and has a pH of 6.8. In a study conducted Van der Bijl & de Waal (1994:299–303), a low-cost, CMC-based, high viscosity artificial saliva was prepared from constituents readily available in South Africa, and its efficiency in treating xerostomia was clinically evaluated. The artificial saliva solution had a pH of 6.7, which was in line with other commercially available products. Although the viscosity of the solution was higher than that of trademarked products, the majority of the patients found the prepared artificial saliva to be effective in alleviating their symptoms. The artificial saliva had the composition illustrated in Table 2.5:

Table 2.5: Artificial saliva composition

(Van der Bijl & de Waal, 1994:300)

Ingredient	**Quantity (g)**
Carboxymethylcellulose	9,0
KCl	1,2
NaCl	0,84
$MgCl_2$. $6H_2O$	0,06
$CaCl_2$. $2H_2O$	0,16
K_2HPO_4	0,34
Sorbitol solution (70 %)	42,8
Methyl p-hydroxybenzoate	2,0
Solution of egg yellow (1 %)	2,0
Oil of lemon	0,4
Distilled water	1000 ml

Saini et al. (2016:288) investigated the sorption and solubility of heat-cured and self-cured acrylic resins immersed in different solutions. The solutions included distilled water, artificial saliva, denture cleansing solution, a mixture of distilled water and denture cleaning solution and a mixture of artificial saliva and denture cleaning solution. The study indicated that the sorption rate of heat-activated PMMA denture base material was lower when it was stored in an artificial saliva solution than when a distilled water and denture cleansing solution was used. It was therefore concluded that the rate of sorption of PMMA denture base material may be affected by the molecular structure of the solution in which it is immersed. These findings may also be attributed to the difference in solubility parameters between the solution and the material (Ferracane, 2006:214), as well as the varying degrees of viscosity of the various solutions (Dickson, 2020). Similar results were recorded by Zidan et al. (2020:3732), who investigated the long-term sorption and solubility of zirconia-impregnated PMMA nanocomposite in water and artificial saliva. Although the study did not specifically aim to compare the sorption and solubility values recorded in distilled water against the values recorded in artificial saliva, it was noted that the conventional heat-cured specimens soaked in artificial saliva recorded lower sorption and solubility values than those soaked in distilled water.

2.12 Measurement of sorption and solubility for denture base material

The technique used to measure the extent of sorption and solubility of the denture base material is of crucial importance as it will form the basis of the research methodology employed in this study. According to the *Miller-Keane Encyclopedia and Dictionary of Medicine, Nursing and Allied Health* (2003), sorption is the process or state of being sorbed, whether through absorption or adsorption. Sorption can therefore be regarded as the increase in weight or volume of a specimen. As the solubility of a material indicates the mass of soluble substances leaking from a specimen, it can be indicated through the loss of weight or volume of a specimen. The ISO 20795-1 (2013) document establishes a clear guideline for the measurement of sorption and solubility, which should be based upon measurement of the uptake and release of a solute under controlled conditions. This testing is made possible by using an apparatus referred to as a "desiccator". A desiccator is an airtight chamber that can preserve the humidity of its atmosphere by placing a suitable drying agent inside of it, e.g. silica. The document states that the test specimens should be placed inside the desiccator after fabrication, until a constant mass (m_1) across all the specimens is achieved. The volume of the specimens in their conditioned mass is then calculated. The specimens are re-submerged in distilled water for a specified time, after which they are weighed again (m_2). The specimens with weight m_2 will be reconditioned until a constant mass is reached again. This conditioned mass will then be recorded as m_3. Once all the data has been gathered, the formulae supplied by the ISO 20795-1 (2013) document can be used to calculate the sorption and solubility of the specimens (cf. Section 3.7.4).

2.13 Conclusion

This chapter has provided a comprehensive review of the literature relating to dental prostheses and materials. The history of denture base materials has been presented with specific reference to heat-activated PMMA. Sorption and solubility were identified as two major drawbacks of denture base materials and their detrimental effects were documented. Literature pertaining to the mixing ratios, polymerisation cycles and thickness of the denture base was reviewed and these factors were identified as external variables that can negatively influence the rate of sorption and solubility experienced by denture base materials. Measures to reduce the amount of sorption and solubility in denture base material were canvassed and it was found that surface treatment procedures as well as storing the material in an artificial saliva solution may lead to such a reduction. The chapter concluded with the measurement procedures used to calculate the amount of sorption and solubility occurring in denture base materials. The following chapter, Chapter Three, will cover the research methodology employed in this study.

Chapter 3

METHODOLOGY

3.1 Introduction

This chapter provides a thorough description of the methodology of the study. The requirements and parameters set by ISO Standard 20795-1: 2013 (E) for testing material sorption and solubility are carefully reviewed and thereafter the methodology is explained in detail. The aim and objectives of the study are once again stated, together with the research procedures that were followed to achieve the objectives while satisfying the requirements of reliability and validity. This chapter also provides for the specific hypotheses that were tested. The inclusion and exclusion criteria for the study are identified, followed by all the data analysis and management procedures utilised. The chapter concludes with a note on ethical considerations relevant to the study.

3.2 Aim of the study

This study aimed to compare the sorption and solubility rates of surface-treated heat-cured acrylic specimens with those of untreated acrylic specimens, soaked in distilled water and artificial saliva.

3.3 Objectives of the study

To achieve the overall aim of this study, the following objectives were developed:

1. To determine the sorption and solubility of heat-cured acrylic with no surface treatment soaked in distilled water.
2. To determine the sorption and solubility of heat-cured acrylic with no surface treatment soaked in artificial saliva.
3. To determine the sorption and solubility of mechanically polished heat-cured acrylic soaked in distilled water.
4. To determine the sorption and solubility of mechanically polished heat-cured acrylic soaked in artificial saliva.
5. To determine the sorption and solubility of heat-cured acrylic treated with a light-cured varnish soaked in distilled water.
6. To determine the sorption and solubility of heat-cured acrylic treated with a light-cured varnish soaked in artificial saliva.
7. To determine which surface treatment results in the least sorption and solubility of the material.
8. To determine which medium results in the least sorption and solubility of the material.

3.4 Research hypotheses

Sorption and solubility are grouped together by the ISO, and previous studies in this field of research have treated sorption and solubility as complementary attributes. The following hypotheses were formulated in order to achieve the objectives listed above:

3.4.1 Hypothesis 1

H_0: The heat-cured test specimens that received no surface treatment soaked in distilled water will not have lower sorption and solubility values than those that received no surface treatment soaked in artificial saliva.

$H_{a:}$ The heat-cured test specimens that received no surface treatment soaked in distilled water will have lower sorption and solubility values than those that received no surface treatment soaked in artificial saliva.

3.4.2 Hypothesis 2

H_0: The heat-cured test specimens that were mechanically polished and soaked in distilled water will not have lower sorption and solubility values than the specimens that received no surface treatment soaked in distilled water.

$H_{a:}$ The heat-cured test specimens that were mechanically polished and soaked in distilled water will have lower sorption and solubility values than the specimens that received no surface treatment soaked in distilled water.

3.4.3 Hypothesis 3

H_0: The heat-cured test specimens that were mechanically polished and soaked in artificial saliva will not have lower sorption and solubility values than the specimens that received no surface treatment soaked in artificial saliva.

$H_{a:}$ The heat-cured test specimens that were mechanically polished and soaked in artificial saliva will have lower sorption and solubility values than the specimens that received no surface treatment soaked in artificial saliva.

3.4.4 Hypothesis 4

H_0: The heat-cured test specimens that were treated with a light-cured varnish and soaked in distilled water will not have lower sorption and solubility values than the specimens that received no surface treatment soaked in distilled water.

$H_{a:}$ The heat-cured test specimens that were treated with a light-cured varnish and soaked in distilled water will have lower sorption and solubility values than the specimens that received no surface treatment soaked in distilled water.

3.4.5 Hypothesis 5

H_0: The heat-cured test specimens that were treated with a light-cured varnish and soaked in artificial saliva will not have lower sorption and solubility values than the specimens that received no surface treatment soaked in artificial saliva.

$H_{a:}$ The heat-cured test specimens that were treated with a light-cured varnish and soaked in artificial saliva will have lower sorption and solubility values than the specimens that received no surface treatment soaked in artificial saliva.

3.4.6 Hypothesis 6

H_0: The heat-cured test specimens that were treated with a light-cured varnish will not have lower sorption and solubility values than the specimens that were mechanically polished.

$H_{a:}$ The heat-cured test specimens that were treated with a light-cured varnish will have lower sorption and solubility values than the specimens that were mechanically polished.

3.4.7 Hypothesis 7

H_0: The heat-cured test specimens soaked in distilled water will not have lower sorption and solubility values than those soaked in artificial saliva.

$H_{a:}$ The heat-cured test specimens soaked in distilled water will have lower sorption and solubility values than those soaked in artificial saliva.

In the case where only one of the two phenomena in this study are in association with the relevant hypothesis, the hypothesis will be recorded as partially accepted.

3.5 Study design

An experimental study design was utilised for this research. Experimental study designs are used to predict and understand phenomena by investigating the relationships between the various relevant variables. During the experimental research, one variable is manipulated while the rest are controlled to see whether the manipulation has any effect (Blakstad, 2008). As this study aimed to determine the effect of surface treatments on the sorption and solubility of heat-cured PMMA, soaked in distilled water and artificial saliva, an experimental study design was used to test the individual hypotheses developed in accordance with a range of applicable variables.

3.6 Study sample

3.6.1 Description of the study sample

As the aim of the research was to compare the sorption and solubility rates of surface-treated, heat-cured acrylic specimens with those of untreated acrylic specimens, soaked in distilled water and artificial saliva, this study falls into the fields of both dental technology and chemistry, under the general umbrella of dental health. While the concept and relevance of the study and the processing methods and materials that it uses belong to the field of dental technology, the reactions and processes that occurred between the relevant materials and substances were chemically based. The *Cambridge Dictionary* (2019) defines chemistry as “the scientific study of the basic characteristics of substances and the ways in which they react or combine”.

3.6.2 Sample size

The (ISO) 20795-1 (2013) E requires one to fabricate five specimens of which, in order to qualify, at least four must comply with ISO requirements. A review of four studies that investigated the sorption and solubility of denture base material had an average of 9.25 specimens per variable group. The sample sizes used in these studies are summarised as follows:

- Figuerôa et al. (2018: 1-7) investigated porosity, water sorption and solubility of denture base acrylic resins polymerised conventionally or in a microwave. He had a total sample population of 20 specimens of which ten were polymerised conventionally and ten polymerised in a microwave.
- Engelbrecht (2010) investigated the factors influencing sorption, solubility and cytotoxicity of a heat-cured denture base polymer. As this was a more comprehensive study with more variables, the author had a total sample population of 116 specimens. However, only 24

(control n=12) specimens were made for testing the effect of mechanical polishing on the sorption and solubility of the heat-cured denture base material.

- Nguyen et al. (2017: 47-52) investigated the water sorption and solubility of polyamide denture base materials. A total sample size of 30 specimens was recorded, with 10 specimens per variable group.
- Saini et al. (2016: 288) compared the sorption and solubility of heat-cure and self-cure acrylic resins submersed in different solutions. The author had a total sample population of 25, with five specimens per variable group.

To produce a justifiable result and based on the number of specimens used in previous studies, it was decided to prepare 15 specimens per variable group. This resulted in a total sample size of 90 specimens. A review of analogous research indicated that this number substantially exceeds the sample size of any previous study.

3.7 Data collection procedure

For this research, the sorption and solubility ratios of heat-cured PMMA, soaked in both distilled water and artificial saliva, were determined pre- and post-surface treatment by mechanical polishing and light-cured varnish. A total of 90 test specimens in six groups were fabricated for the study as follows:

- Group A – 15 untreated specimens fabricated from Vertex™ *Rapid Simplified* heat-cured denture base material that were soaked in grade two distilled water (Control).
- Group B – 15 untreated specimens fabricated from Vertex™ *Rapid Simplified* heat-cured denture base material that were soaked in artificial saliva.
- Group C – 15 mechanically polished specimens fabricated from Vertex™ *Rapid Simplified* heat-cured denture base material that were soaked in grade two distilled water.
- Group D – 15 mechanically polished specimens fabricated from Vertex™ *Rapid Simplified* heat-cured denture base material that were soaked in artificial saliva.
- Group E – 15 specimens treated with a light-cured varnish fabricated from Vertex™ *Rapid Simplified* heat-cured denture base material that were soaked in grade two distilled water.
- Group F – 15 specimens treated with a light-cured varnish fabricated from Vertex™ *Rapid Simplified* heat-cured denture base material that were soaked in artificial saliva.

The sorption and solubility of these groups were calculated and analysed accordingly. The experiments conducted for sorption and solubility testing, as well as the specifications of the

polishing procedure, were in accordance with the International Standard Organisation (ISO) 20795-1 (2013) E document.

3.7.1 Preparation of specimens

Vertex™ *Rapid Simplified* heat-cured denture base material was the material of choice for this study. It has established itself as a popular PMMA material in dental laboratories due to its rapid curing time and favourable physical and mechanical properties. Other options such as *Metrocryl Rapid Cure* from Metrodent™, *Heat Cure Denture Base Material* from Excel Formula™ and Vertex™ *Regular* were possible alternatives, but the nature of this study and laboratory environments in the industry recommended Vertex™ *Rapid Simplified*.

All specimens were prepared in the Dental Sciences Faculty at CPUT and tested at the Oral Health Centre of UWC as that Centre had the required scales, desiccators and other measuring instruments. The laboratory environment was controlled at 23 (± 2) °C and at a relative humidity of 50 (± 10%). A total of 90 specimens was prepared using Type One, Class One (ISO classification) denture base polymer (Vertex™ *Rapid Simplified).* To produce the most accurate results possible and strictly to follow ISO protocols, the researcher used the same mould for the fabrication of all 90 specimens. This created a major time constraint. Discrepancies were more likely to arise as a result of the time difference between the fabrication of specimens, so it was decided to test each variable group individually. All ISO 20795 -1:2013E protocols for testing sorption and solubility and manufacturers' recommendations were always stringently respected.

The stainless-steel mould and cover were custom made, with a slight design change to conform with what is specified by ISO 20795-1: 2013 (E) (see Appendix D, Figure 1). The portion of the mould housing the specimen accorded with the dimensions prescribed by ISO 20795-1: 2013 (E) to test for sorption and solubility of heat-cured PMMA material, but the aligning mechanism of the two parts was modified to ensure optimum accuracy of the specimens produced. This was done by milling the edge of the mould to create a lip onto which the recessed cover fitted. This modification allowed the two parts of the mould to align accurately for every specimen fabricated and prevented any movement between the two halves during the investing and processing procedures. The mould and cover were invested in a two-part denture flask with type one plaster, mixed according to the manufacturer's recommendation. One half of the flask contained the mould and the other half the cover (see Appendix E, Figure 2).

As specified by ISO 20795-1: 2013 (E), all the specimens were made from a single retail package, with sufficient material to carry out all the specified tests, plus an allowance for any tests that needed to be repeated. For each specimen, a separate mix was made as specified by ISO. A calibrated *Denver Instruments S-403SN* balance scale accurate to 1 mg and *Biohit Proline Pipette (100-1000µl)* were used to measure the liquid-to-powder ratio of 1 ml: 2.3g recommended for *Vertex™ Rapid Simplified* heat-cured denture base material. The powder was weighed in a clean resi-mix bowl containing no foreign bodies. For each measure of monomer, a new pipette tip was used. For each specimen, 2.3 grams of powder were weighed and mixed with one millilitre of liquid. *Vertex™* recommends that the material is mixed for 30 seconds after which it has a dough time of 15 minutes and a working time of 30 minutes. After mixing, a timer was set for 15 minutes to signal the completion of the dough time.

Once the material achieved its dough-like structure, it was removed from the resi-mix bowl and placed into the stainless-steel mould. A polythene sheet from *Metrodent™* was placed over the mixed material to create a buffer between the material and the stainless-steel cover of the mould. The polythene sheet remained in the mould throughout the processing procedure. The flasks were closed and placed in a pneumatic press. Pressure of two bars was applied and maintained until no loss in pressure was observed, after which the flask was removed and placed in its respective clamp. The flask was put into a curing bath containing water heated to 100°C and cured for 20 minutes as recommended by the manufacturer. Once complete, the flask was removed and allowed to bench cool until it reached the ambient temperature. After cooling, the specimens were carefully removed from the mould and the flash was removed using a scalpel blade (see Appendix E, Figure 3). The specimens were assessed to ensure they complied with ISO requirements, after which they were placed in individual airtight bags. The specimens were stored in a fridge kept at a constant temperature of 7°C. Once all the specimens were fabricated, they were removed to receive their allocated surface treatment.

3.7.2 Surface treatment

All the specimens, including those that received no surface treatment, were ground with pumice and a wet muslin wheel for one minute per surface as indicated by ISO 20795-1:2013(E). A fresh batch of pumice of even consistency was mixed for each specimen. To achieve a uniform surface, the specimens were ground using a circular motion.

Because the specimens were only 0.5mm thick, an additional two specimens were fabricated from the same Vertex™ *Rapid Simplified* material before the commencement of the study. These specimens were intended to supplement the specimens being utilised in this study and were marked with a marker to indicate their purpose. The support specimens were stacked behind the specimens undergoing both finishing and mechanical polishing procedures. During mechanical polishing, the additional specimens not only provided additional support but also assisted with heat dissipation. The polishing process exposes the specimens to considerable frictional force, resulting in the generation of heat. Excess heat generation can burn the surface of the specimens or result in their warping.

Mechanical polishing and the application of a light-cured varnish were the two applications used to treat the surfaces of the designated specimens. The specimens were mechanically polished in circular motions with intermittent contact for two minutes per surface using an unstitched muslin wheel and Vertex™ *High Gloss Polishing Paste.* After polishing, the specimens were visually inspected to ensure they complied with ISO requirements, by presenting a smooth surface with a high gloss. The application surface of the specimens that were treated with *Optiglaze*™ was wiped with Vertex™ *Rapid Simplified* monomer, to remove any smear layer from the surface of the specimen. A thin layer of *Optiglaze*™ protective coating agent was applied, after which it was cured in a light-curing unit. Once the respective surface treatment procedures were complete, the specimens were marked using a black waterproof marker. Each sample group was named, using the letters A–F to indicate the sample population and the numbers 1–15 to number the specimens.

3.7.3 Preparation of artificial saliva

The formula for the artificial saliva solution used for this study was published by Van der Bijl & de Waal (1994:299–303) in their article “Preparation and clinical evaluation of a high viscosity saliva substitute”. As the objective of their study was to find a low-cost artificial saliva substitute that could be prepared from constituents readily available in South Africa, it was thought to be ideal for the context of this study. 3600ml of grade two distilled water was boiled and mixed with 35g of carboxymethylcellulose in a conical flask. The flask was sealed to prevent any evaporation of liquid and placed on a magnetic stirrer with a hot plate for 24 hours to allow the carboxymethylcellulose to thoroughly dissolve. The following constituents were then weighed and dissolved in 200ml of grade two distilled water in the following order: NaCl (3,36g), KCl (4,8g), $MgCl_2$ (0,24g), K_2HPO_4 (1,36g) and $CaCl_2$ (0,64g). This mixture was then added to the carboxymethylcellulose mixture, together with eight grams of methyl-p-hydroxybenzoate dissolved in 200ml of grade two distilled water. Sorbitol, the oil of lemon and colouring dissolved in alcohol were omitted from the mixture as these ingredients are added to improve

the taste and aesthetic appeal of the solution, neither of which was applicable to its intended experimental use.

3.7.4 Sorption and solubility testing

The specimens were removed from their individual air-sealed bags and placed in the custom-built drying rack, keeping them parallel and separated (see Figure 8.4). The rack was put into a desiccator containing freshly dried silica gel, which had been dried for 300 (± 10) minutes, at 130 (± 10 °C) (see Figure 8.5). The desiccator was placed in an incubator set at a constant temperature of 37 (± 1 °C) for 23 (± 1) hours. Once the time elapsed, the desiccator was removed from the incubator and the rack containing the specimens was placed in a second desiccator, containing freshly dried silica gel. The second desiccator was kept at 23 (± 2) °C. After 60 (± 10) minutes, the specimens were removed and weighed using an analytical balance scale (*Mettler AE 240*) accurate to 0,01 mg. The desiccator was sealed throughout the weighing procedure, except for the shortest time when the individual specimens were removed and replaced using polymer-coated tweezers.

After each weighing procedure, the mass of each specimen was recorded as W, with a numerical suffix indicating the weighing order such as W1, W2, and W3. This was the first value that was recorded. The value played no active role in determining the sorption and solubility of the specimens but needed to be recorded to calculate the conditioned mass of the specimens. The drying process described above was referred to as the conditioning process. After all the specimens were individually weighed, the silica gel in the desiccator was replaced with freshly dried silica gel and the desiccator containing the rack with specimens was put back into the incubator set at 37 (± 1) °C for 23 (± 1) hours. The conditioning process was repeated and continued until the loss in mass of each specimen was not more than 0.2 mg between two successive conditioning procedures, i.e. W1 – W2 < 0.2 mg. The conditioned mass was recorded as m_1. Once all the specimens reached a conditioned mass, the volume of the conditioned specimens was calculated and recorded as V. The volume was calculated using the mean of three diameter measurements and five thickness measurements of each specimen. The thickness measurements were made at the centre and at 4 equally-spaced locations around the circumference of the specimen. m_1 and V will therefore represent the mass and volume of the specimens before any sorption has taken place.

After calculating the volume of each specimen, the specimens were put back in the drying rack, which was submerged in grade two distilled water for groups A, C and E and in an artificial saliva solution for groups B, D and F. The rack was submersed in a glass bowl for 7 days (± 2

hours) and kept in an incubator set at 37 (± 1) °C. The bowl was closed with plastic wrap to prevent the evaporation of any liquid (see Appendix E, Figure 6). Once the indicated period had elapsed, the specimens were removed from the liquid with polymer-coated tweezers, wiped with a clean, dry towel until no visible moisture was present, waved in the air for 15 (± 1) seconds and weighed one by one within 60 (± 10) seconds after their removal from the liquid. This mass was recorded as m_2 and represented the increase in mass due to sorption. After recording m_2, the specimens were again reconditioned to a constant mass. The conditioned mass was recorded as m_3 this time round and represented the loss in mass of the specimen due to solubility. Using the recorded variables, and formulae provided by ISO 20795-1:2013(E), the sorption and solubility of the specimens were calculated according to the following formulae:

Water sorption (Wsp) was calculated in µg/mm³ using the formula recommended by ISO 20795-1:2013(E):

$$Wsp = \frac{m2 - m3}{V}$$

Water solubility (Wsl) was calculated in µg/mm³ using the formula recommended by ISO 20795-1:2013(E):

$$Wsl = \frac{m1 - m3}{V}$$

A *Mettler AE 240* analytical balance scale mounted on a granite top was used to provide readings accurate to 0,1mg and indicating up to five decimal places. The weighing plate of the scale is situated in a glass enclosure with sliding doors to prevent any external variables such as moisture in the air from affecting the weight reading of the specimen. The thickness readings were done with a *Toolquip & Allied Digital Outside Micrometer 0-25mm* indicating up to three decimal places, and the diameter readings with a *Mitutoyo CD-15 DCX Digital Calliper* indicating up to 2 decimal places. All the instruments were calibrated by approved entities prior to the commencement of the study.

A summarised version of the sorption and solubility procedure as stipulated by ISO Standard 20795-1: 2013 (E) for denture base polymers is illustrated in Figure 3.1, below.

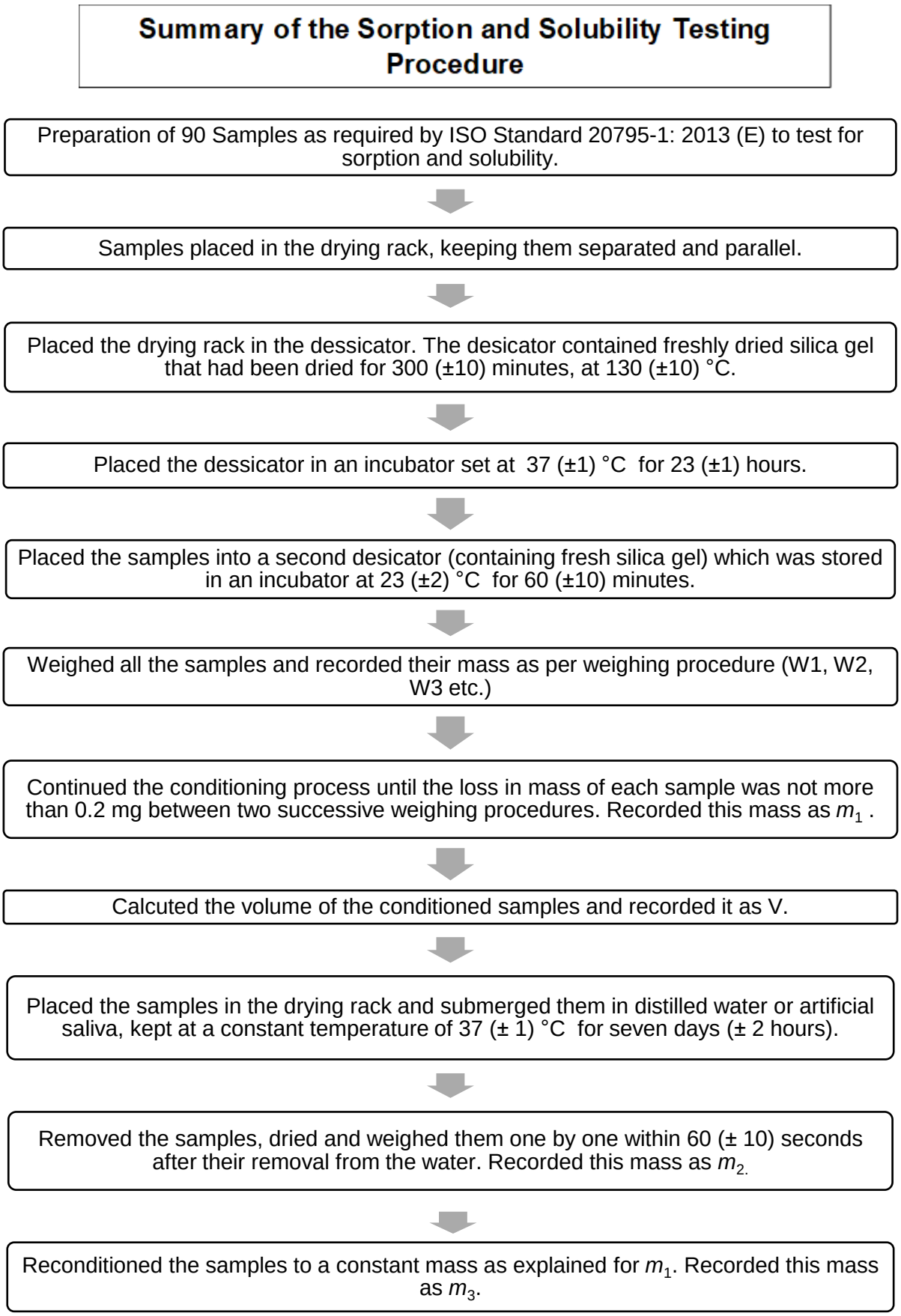

Figure 3.1: Sorption and solubility testing procedure

(International Organisation for Standardisation, 2013)

3.8 Inclusion and exclusion criteria

3.8.1 Inclusion criteria

The following inclusion criteria were applied for the specimens in this study:

- Only specimens that fall within the parameters set by the ISO Standard 20795-1: 2013 (E) document for testing sorption and solubility were deemed viable.
- Only specimens manufactured from *Vertex™ Rapid Simplified* heat-cured denture base material were used.
- The specimens needed to have a diameter of 50 (± 1) mm.
- The specimens needed to have a thickness of 0.5 (± 0.1) mm.
- All specimens had to be fabricated from the same mould.
- Only measuring instruments and scales that had been professionally calibrated were used.
- Only specimens treated with *Optiglaze™* or *Vertex™ High Gloss Polishing Paste* were accepted as specimens with a surface treatment.
- The measurements of all specimens had to be verified by an independent party.

3.8.2 Exclusion criteria

Any specimens that did not meet the parameters stated in the inclusion criteria were excluded from testing.

3.9 Data analysis

The mass and volume of the specimens were the two variables that were used to determine the outcome of the study. A custom-designed Microsoft Excel™ data capturing form (see Appendix B) was used to record the data. The following variables were recorded:

1. After fabrication, the specimens underwent a conditioning process to reach a constant mass. This was the point at which the moisture leaving the material reached equilibrium. The mass of each specimen, after each weighing procedure, was recorded as W, with a numerical suffix indicating the conditioning process number, such as W1, W2, W3. This was the first variable recorded. This variable played no active role in determining the sorption and solubility of the specimens but was had to be recorded in order to calculate the conditioned mass of the specimen.
2. The conditioned mass of the specimen was recorded as m_1.
3. The volume of the conditioned specimens was recorded as V.

4. The increase in mass of the specimens due to sorption was recorded as m_2.
5. The loss in mass of the specimen due to solubility was recorded as m_3.

This data was then used to calculate the sorption and solubility of the specimens using the formulae provided by the ISO Standard 20795-1:2013 (E) (see Section 3.7.4, above). The results were tabulated, indicating Wsp and Wsl of the surface-treated specimens and those submerged in artificial saliva against the control group.

Descriptive statistics were used to summarise the recorded data by means of central tendency (mean and median) and measures of variability (standard deviation, standard error, range and the minimum and maximum variables). Inferential statistics were then used to determine the associations or relationships between the sorption and solubility of the surface-treated specimens and those submerged in artificial saliva against the control group. The data was analysed using the One- and Two-Way analysis of variance. Where the p-value was found to be less than 0.05, it was concluded that a significant difference between the variables existed. If the p-value was found to be larger than 0.05, it could not be concluded that a significant difference existed. The Tukey-Kramer multiple comparison test was used to indicate significant differences among the means of the different sample groups.

3.10 Data management

All the data was captured on the custom-designed Microsoft Excel™ spreadsheet after each procedure. The electronic files were secured with a password, granting access only to the researcher. After the data for the procedure had been recorded, the spreadsheet was saved on a laptop with the filename suffix updated to reflect the date on which the data was captured and uploaded onto Google Drive. At the end of each day, all the data was further backed up onto a password-controlled external hard drive designated solely for this purpose. All data will be stored and managed according to the CPUT Research Data Management Policy and in line with the CPUT statement on Sharing Research Data. All data will be kept for a period of five years.

3.11 Reliability and validity

3.11.1 Reliability

Reliability is a measure of the consistency, accuracy and repeatability of the research conducted (Chakrabartty, 2013:1). For research to be deemed accurate and trustworthy, the

research instruments used need consistently to produce the same results under the same conditions (Heale & Twycross, 2015:66). To ensure the reliability of the study, ISO 20795-1:2013(E) requirements for testing sorption and solubility were strictly adhered to. This also served to ensure the reproducibility of the study and to set a measurable standard. Furthermore, all research instruments were calibrated by accredited enterprises to ensure that the data obtained from the measurements was accurate and true. Intra operator repeatability and reliability was ensured by fabricating all the specimens from the same mould. Due to Covid-19 restrictions at the time of the study, all measurements made were cross-checked by the researcher after each measuring procedure to ensure accuracy. Finally, with regard to all materials used, all the manufacturers' recommendations for fabrication and processing were strictly adhered to.

3.11.2 Validity

According to Heale and Twycross (2015:66), validity is the extent to which a concept is accurately measured in a quantitative study. In other words, validity refers to how accurately a method measures what it is intended to measure. This study strictly followed the well-established international standards of the ISO 20795-1:2013(E) requirements for calculating the sorption and solubility of denture base materials. Only the precise formulae contained in these requirements were used to calculate the Wsl and Wsp of the material specimens under consideration.

3.12 Ethical considerations

This study did not require the participation of any humans or animals. The study was nevertheless approved by the CPUT Faculty of Health and Wellness Science's Research Committee, and thereafter ethical approval was granted by the Faculty of Health and Wellness Science's Research Ethics Committee on 4th November 2019 (Approval Reference No: CPUT/HW-REC 2019/H13) (see Appendix A).

3.13 Conclusion

Chapter 3 has provided an in-depth account of the methodology employed in the study. The aim and objectives of the study were stated and its hypotheses were comprehensively detailed. The study sample was described, and the specimen size of 90 was justified on the basis of peer-reviewed scientific literature. The inclusion criteria and data collection procedures were detailed, data analysis and management protocols were recorded, and measures for achieving reliability and validity described. The following chapter will present the results obtained from the study.

Chapter 4

RESULTS

4.1 Introduction

This chapter presents the results obtained from the various experiments undertaken for the research. In addition to the narrative text, the results are summarised, first, in terms of descriptive statistics and presented in tables and figures. The objectives are revisited in order to accept, reject or partially accept the hypotheses. Inferential statistics are used in the form of One- and Two-Way Analysis of Variance so that possible associations between variables can be determined. The chapter concludes with a summary of the results, highlighting the findings that are crucial to the overall aim of the study.

4.2 Sorption and solubility of heat-cured acrylic with no surface treatment soaked in distilled water and artificial saliva.

The results for objectives one and two were analysed in order to accept or reject the following hypotheses:

> H_0: The heat-cured test specimens that received no surface treatment soaked in distilled water will not have lower sorption and solubility values than those that received no surface treatment soaked in artificial saliva.
>
> H_a: The heat-cured test specimens that received no surface treatment soaked in distilled water will have lower sorption and solubility values than those that received no surface treatment soaked in artificial saliva.

4.2.1 Objective one: to determine the sorption and solubility of heat-cured acrylic with no surface treatment soaked in distilled water

This sample group consisted of 15 specimens that received no surface treatment and were soaked in distilled water to obtain their saturated mass. All the specimens reached m_1 on the second day of the conditioning process, after which the specimens were soaked for seven days, resulting in m_2 being obtained on the ninth day of the cycle. The specimens were reconditioned, and the entire population reached m_3 on the 11th day (cf. Table 4.1). Table 4.1, below, presents the time cycles for the testing of all the specimens, while Table 4.2 shows the results obtained when sorption and solubility values were measured for the specimens with no surface treatment soaked in distilled water. Figure 4.1 portrays in graphic form the individual Wsl and Wsp values recorded for objective one.

Table 4.1: Time taken for specimens to complete the testing procedure in days

Group:	Length of Testing Procedure (Days)
No Surface Treatment, Distilled Water (A)	11
No Surface Treatment, Artificial Saliva (B)	12
Mechanical Polishing, Distilled Water (C)	11
Mechanical Polishing, Artificial Saliva (D)	12
Light-Cured Varnish, Distilled Water (E)	11
Light-Cured Varnish, Artificial Saliva (F)	11

Table 4.2: Results for "no surface treatment, soaked in distilled water"

	Mean	**Median**	**Std Dev.**	**Std Error**	**Min.**	**Max.**	**Range**
Solubility in µg/mm^3	0.1843	0.1866	0.1367	0.0353	-0.1891	0.4321	0.6212
Sorption in µg/mm^3	22.3690	22.1536	0.8619	0.2225	21.2659	24.5340	3.2681

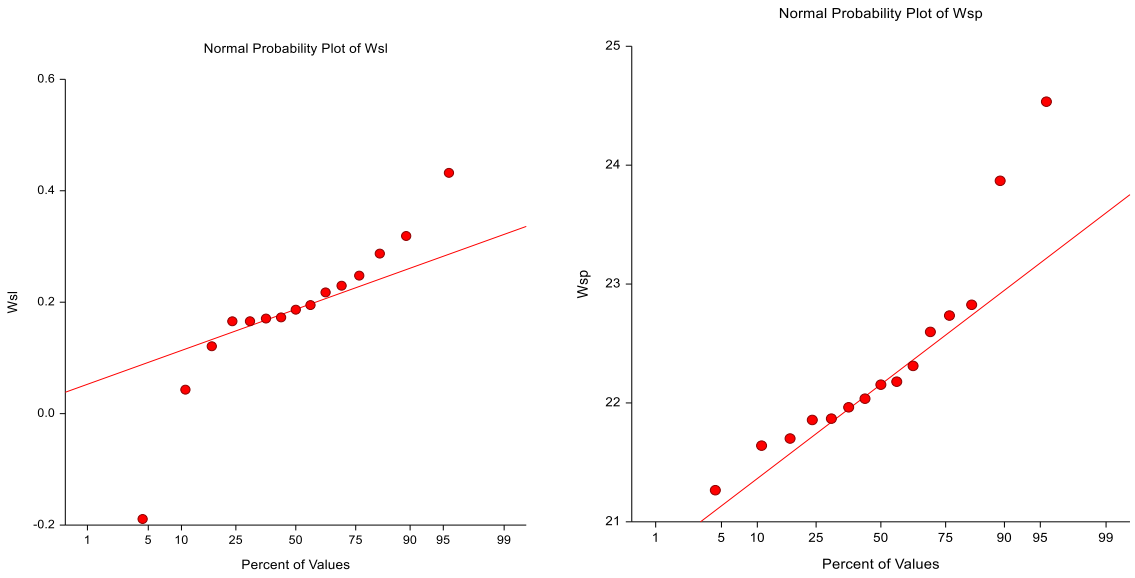

Figure 4.1: Plot graphs indicating the individual Wsl and Wsp values recorded for objective one

4.2.2 Objective two: to determine the sorption and solubility of heat-cured acrylic with no surface treatment soaked in artificial saliva

This sample group consisted of 15 specimens that received no surface treatment and were soaked in artificial saliva to obtain their saturated mass. All the specimens reached m_1 on the second day of the conditioning process, after which the specimens were soaked for seven days, resulting in m_2 being obtained on the ninth day of the cycle. The specimens were reconditioned, and the entire population reached m_3 on the 12th day (cf. Table 4.1). Table 4.3 presents the results that were obtained when sorption and solubility values were measured for the specimens with no surface treatment soaked in artificial saliva.

Table 4.3: Results for "no surface treatment, soaked in artificial saliva"

	Mean	Median	Std Dev.	Std Error	Min.	Max.	Range
Solubility in µg/mm^3	0.0620	0.0904	0.0678	0.0175	-0.0549	0.1322	0.1870
Sorption in µg/mm^3	21.7813	21.7951	0.3916	0.1011	21.1097	22.4078	1.2981

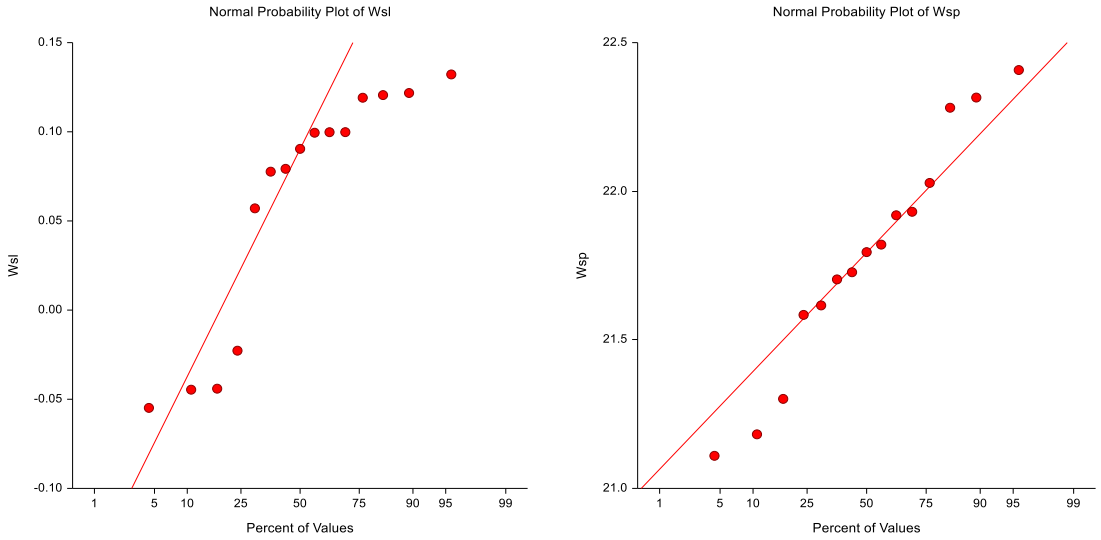

Figure 4.2: Plot graphs indicating the individual Wsl and Wsp values recorded for objective two

4.2.3 Comparison of means for *"No surface treatment, soaked in distilled water"* and *"No surface treatment, soaked in artificial saliva"*

The specimens that received no surface treatment and were soaked in distilled water obtained mean Wsp and Wsl values of 22.3690 µg/mm^3 and 0.1843 µg/mm^3, respectively (cf. Table 4.2). When these means are compared to the mean Wsp (21.7813 µg/mm^3) and Wsl (0.0620 µg/mm^3) values obtained by the specimens that received no surface treatment soaked in artificial saliva, it appears that the mean sorption and solubility values were lower for heat-cured acrylic specimens that were soaked in artificial saliva, as opposed to the specimens that received no surface treatment soaked in distilled water.

4.3 Objective three: to determine the sorption and solubility of mechanically-polished, heat-cured acrylic soaked in distilled water

The results for objective three were analysed in order to accept or reject the following hypotheses:

H_0: The heat-cured test specimens that have been mechanically polished and soaked in distilled water will not have lower sorption and solubility values than the specimens that received no surface treatment soaked in distilled water.

H_a: The heat-cured test specimens that have been mechanically polished and soaked in distilled water will have lower sorption and solubility values than the specimens that received no surface treatment soaked in distilled water.

This sample group consisted of 15 specimens that were mechanically polished and soaked in distilled water to obtain their saturated mass. All the specimens reached m_1 on the second day of the conditioning process, after which the specimens were soaked for seven days, resulting in m_2 being obtained on the ninth day of the cycle. The specimens were reconditioned, and the entire population reached m_3 on the 11th day (cf. Table 4.1). Table 4.4 presents the results that were obtained when sorption and solubility values were measured for the specimens that were mechanically polished and soaked in distilled water.

Table 4.4: Results for "mechanically polished, soaked in distilled water"

	Mean	Median	Std Dev.	Std Error	Min.	Max.	Range
Solubility in µg/mm^3	0.1593	0.1600	0.0457	0.0118	0.0683	0.2315	0.1632
Sorption in µg/mm^3	21.8613	21.9569	0.2676	0.0691	21.4994	22.3403	0.8409

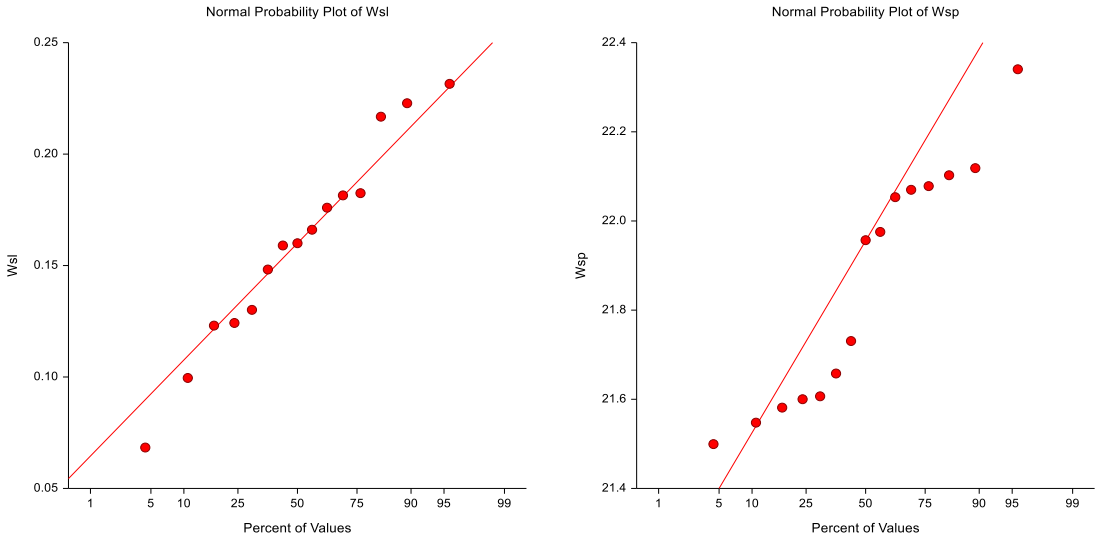

Figure 4.3: Plot graphs indicating the individual Wsl and Wsp values recorded for objective three

4.3.1 Comparison of means for *"Mechanically polished, soaked in distilled water"* and *"No surface treatment, soaked* in *distilled water"*

The specimens that were mechanically polished and soaked in distilled water obtained mean Wsp and Wsl values of 21.8613 µg/mm^3 and 0.1593 µg/mm^3 respectively (see Table 4.4, above). When these means are compared to the mean Wsp (22.3690 µg/mm^3) and Wsl (0.1843µg/ mm^3) values obtained by the specimens that received no surface treatment soaked in distilled water (Table 4.1), it is indicated that the mean sorption and solubility values were lower for heat-cured acrylic specimens that were mechanically polished and soaked in distilled water, as opposed to the specimens that received no surface treatment soaked in distilled water.

4.4 Objective four: to determine the sorption and solubility of mechanically-polished, heat-cured acrylic soaked in artificial saliva

The results for objective four were analysed in order to accept or reject the following hypotheses:

> H_0: The heat-cured test specimens that have been mechanically polished and soaked in artificial saliva will not have lower sorption and solubility values than the specimens that received no surface treatment soaked in artificial saliva.
>
> $H_{a:}$ The heat-cured test specimens that have been mechanically polished and soaked in artificial saliva will have lower sorption and solubility values than the specimens that received no surface treatment soaked in artificial saliva.

This sample group consisted of 15 specimens that were mechanically polished and soaked in artificial saliva to obtain their saturated mass. All the specimens reached m_1 on the second day of the conditioning process, after which the specimens were soaked for seven days, resulting in m_2 being obtained on the ninth day of the cycle. The specimens were reconditioned, and the entire population reached m_3 on the 12th day (cf. Table 4.1). Table 4.5 presents the results obtained when sorption and solubility values were measured for the specimens that were mechanically polished and soaked in artificial saliva.

Table 4.5: Results for "mechanically polished, soaked in artificial saliva"

	Mean	Median	Std Dev.	Std Error	Min.	Max.	Range
Solubility in µg/mm^3	0.0225	0.0333	0.0525	0.0136	-0.0457	0.1330	0.1787
Sorption in µg/mm^3	21.8634	21.8916	0.3460	0.0893	21.1634	22.5142	1.3507

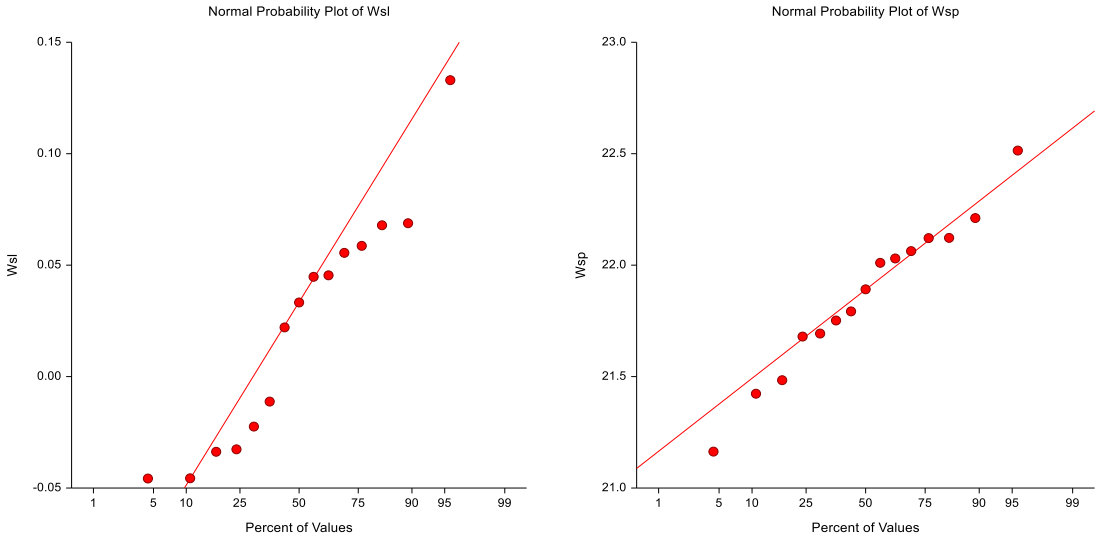

Figure 4.4: Plot graphs indicating the individual Wsl and Wsp values recorded for objective four

4.4.1 Comparison of means for *"Mechanically polished, soaked in artificial saliva"* and *"No surface treatment, soaked in artificial saliva"*

The specimens that were mechanically polished and soaked in artificial saliva obtained mean Wsp and Wsl values of 21.8634 µg/mm^3 and 0.0225 µg/mm^3 respectively (see Table 4.5, above). When these means are compared with the mean Wsp (21.7813 µg/mm^3) and Wsl (0.0620 µg/mm^3) values obtained by the specimens that received no surface treatment soaked in artificial saliva (Table 4.3), it appears that the mean solubility value was lower and the mean sorption value was higher for heat-cured acrylic specimens that were mechanically polished and soaked in artificial saliva, than was the case for the specimens that received no surface treatment soaked in artificial saliva.

4.5 Objective five: sorption and solubility of heat-cured acrylic treated with a light-cured varnish soaked in distilled water

The results for objective five were analysed in order to accept or reject the following hypotheses:

> H_0: The heat-cured test specimens that were treated with a light-cured varnish and soaked in distilled water will not have lower sorption and solubility values than the specimens that received no surface treatment soaked in distilled water.
>
> $H_{a:}$ The heat-cured test specimens that have been treated with a light-cured varnish and soaked in distilled water will have lower sorption and solubility values than the specimens that received no surface treatment soaked in distilled water.

This sample group consisted of 15 specimens that were treated with a light-cured varnish and soaked in distilled water to obtain their saturated mass. All the specimens reached m_1 on the second day of the conditioning process, after which the specimens were soaked for seven days, resulting in m_2 being obtained on the ninth day of the cycle. The specimens were reconditioned, and the entire population reached m_3 on the 11th day (cf. Table 4.1). Table 4.6 presents the results that were obtained when sorption and solubility values were measured for the specimens that were treated with a light-cured varnish and soaked in distilled water.

Table 4.6: Results for "light-cured varnish, soaked in distilled water"

	Mean	Median	Std Dev.	Std Error	Min.	Max.	Range
Solubility in µg/mm^3	0.2406	0.2492	0.1080	0.0279	0.0223	0.4191	0.3968
Sorption in µg/mm^3	21.3713	21.3372	0.2873	0.0742	20.8905	21.9269	1.0364

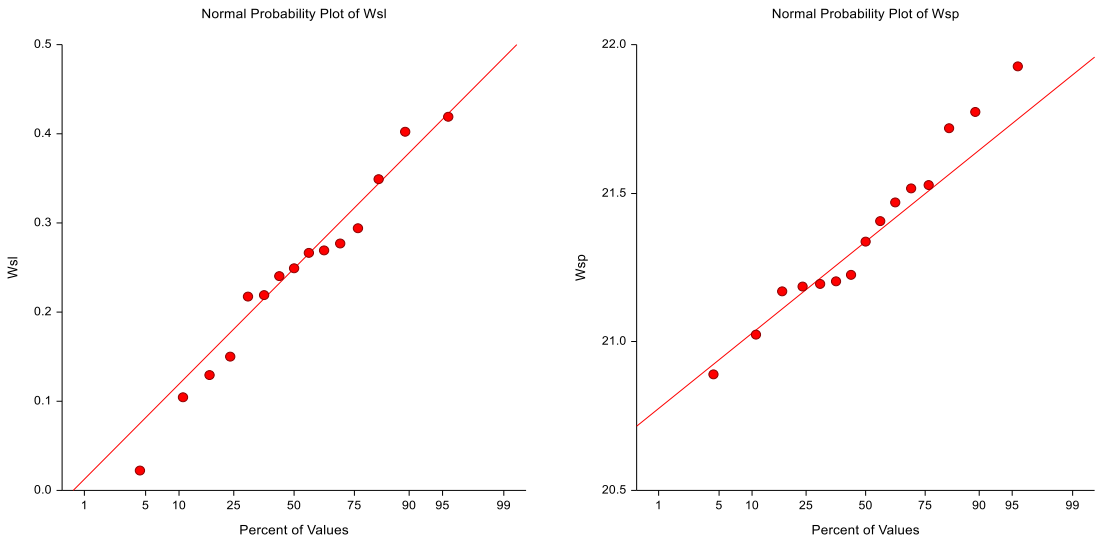

Figure 4.5: Plot graphs indicating the individual Wsl and Wsp values recorded for objective five

4.5.1 Comparison of means for *"Light-cured varnish, soaked in distilled water"* and *"No surface treatment, soaked in distilled water"*

The specimens that were treated with a light-cured varnish and soaked in distilled water obtained mean Wsp and Wsl values of 21.3713 µg/mm^3 and 0.2406 µg/mm^3 respectively (Table 4.6). When these means are compared with the mean Wsp (22.3690 µg/mm^3) and Wsl (0.1843 µg/ mm^3) values obtained by the specimens that received no surface treatment soaked in distilled water (Table 4.1), it is indicated that the mean sorption value was lower and the mean solubility value was higher for heat-cured acrylic specimens that were treated with the light-cured varnish and soaked in distilled water, as opposed to the specimens that received no surface treatment soaked in distilled water.

4.6 Objective six: sorption and solubility of heat-cured acrylic treated with a light-cured varnish soaked in artificial saliva

The results for objective six were analysed in order to accept or reject the following hypotheses:

H_0: The heat-cured test specimens that have been treated with a light cure varnish and soaked in artificial saliva will not have lower sorption and solubility values than the specimens that received no surface treatment soaked in artificial saliva.

H_a: The heat-cured test specimens that have been treated with a light cure varnish and soaked in artificial saliva will have lower sorption and solubility values than the specimens that received no surface treatment soaked in artificial saliva.

This sample group consisted of 15 specimens that were treated with a light-cured varnish and soaked in artificial saliva to obtain their saturated mass. All the specimens reached m_1 on the second day of the conditioning process, after which the specimens were soaked for seven days, resulting in m_2 being obtained on the ninth day of the cycle. The specimens were reconditioned, and the entire population reached m_3 on the 11th day (cf. Table 4.1). Table 4.7 presents the results that were obtained when sorption and solubility values were measured for the specimens that were treated with a light-cured varnish and soaked in artificial saliva.

Table 4.7: Results for "light-cured varnish, soaked in artificial saliva"

	Mean	Median	Std Dev.	Std Error	Min.	Max.	Range
Solubility in µg/mm^3	0.1886	0.2034	0,1104	0.0285	-0.1672	0.3007	0.4679
Sorption in µg/mm^3	21.6997	21.7339	0.3479	0.0898	21.1888	22.3174	1.1286

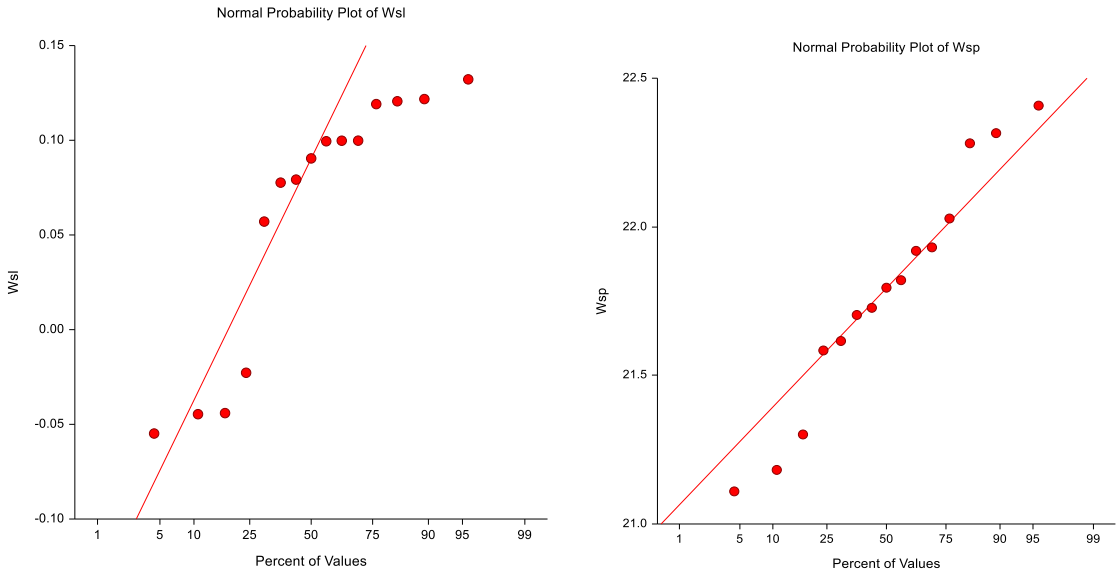

Figure 4.6: Plot graphs indicating the individual Wsl and Wsp values recorded for objective six

4.6.1 Comparison of means for *"Light-cured varnish, soaked in artificial saliva"* and *"No surface treatment, soaked in artificial saliva"*

The specimens that were treated with a light-cured varnish and soaked in artificial saliva obtained mean Wsp and Wsl values of 21.6997 µg/mm^3 and 0.1886 µg/mm^3 respectively (cf. Table 4.6). When these means are compared to the mean Wsp (21.7813 µg/mm^3) and Wsl (0.0620 µg/ mm^3) values obtained by the specimens that received no surface treatment soaked in artificial saliva (cf. Table 4.2), it is indicated that the mean sorption value was lower and the mean solubility value was higher for heat-cured acrylic specimens that were treated with the light-cured varnish and soaked in artificial saliva, than was the case with the specimens that received no surface treatment soaked in artificial saliva.

4.7 Objective seven: surface treatment resulting in the least sorption and solubility of heat-cured acrylic material

The results for objective seven were analysed in order to accept or reject the following hypotheses:

> H_0: The heat-cured test specimens that have been treated with a light-cured varnish will not have lower sorption and solubility values than the specimens that have been mechanically polished.
>
> H_a: The heat-cured test specimens that have been treated with a light-cured varnish will have lower sorption and solubility values than the specimens that have been mechanically polished.

This sample group consisted of 60 specimens that were either mechanically polished or treated with a light cure varnish. The mean sorption and solubility values for each surface treatment were calculated and compared. Table 4.8 presents the results that were obtained when sorption and solubility values were measured for the specimens that were mechanically polished or treated with a light-cured varnish.

Table 4.8: Mean sorption and solubility values for surface-treated specimens

	Mechanical Polishing	**Light-Cured Varnish**
Solubility in µg/mm^3	0.0909	0.2146
Sorption in µg/mm^3	21.8624	21.5355

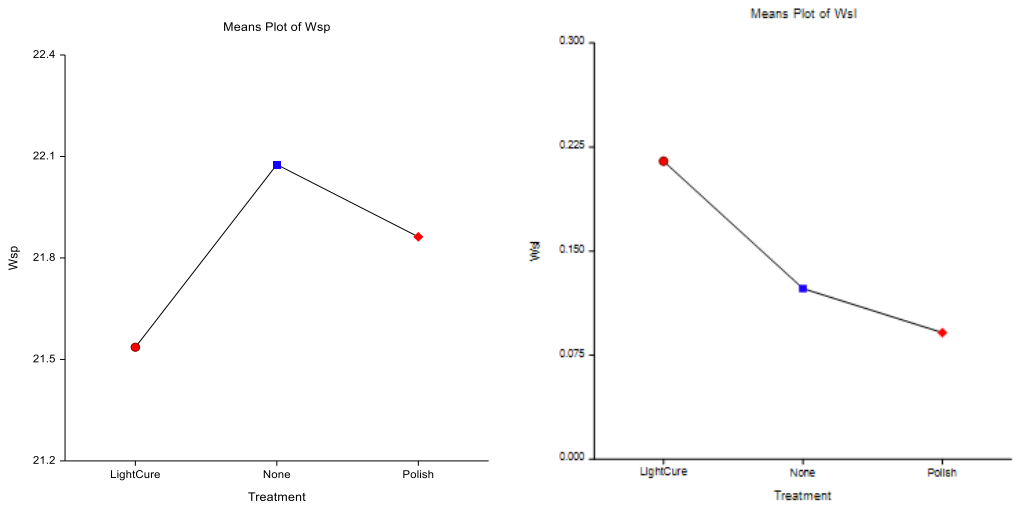

Figure 4.7: Mean sorption and solubility plot for surface treated specimens

4.7.1 Comparison of means for *"Mechanical polishing"* and *"Light-cured varnish"*

The specimens that were treated with a light-cured varnish obtained mean Wsp and Wsl values of 21.5355 µg/mm^3 and 0.2146 µg/mm^3 respectively (Table 4.7). When these means are compared to the mean Wsp (21.8624 µg/mm^3) and Wsl (0.0909 µg/ mm^3) values obtained by the specimens that were mechanically polished (cf. Table 4.7), it is revealed that the mean sorption value was lower and the mean solubility value was higher for heat-cured acrylic specimens that were treated with the light-cured varnish, as opposed to the specimens that were mechanically polished.

4.8 Objective eight: medium in which the heat-cured acrylic material is soaked that results in the least sorption and solubility of the material

The results for objective eight were analysed in order to accept or reject the following hypotheses:

H_0: The heat-cured test specimens soaked in distilled water will not have lower sorption and solubility values than those soaked in artificial saliva.

H_a: The heat-cured test specimens soaked in distilled water will have lower sorption and solubility values than those soaked in artificial saliva.

This sample group consisted of 90 specimens that were soaked either in distilled water or in artificial saliva. The mean sorption and solubility values for each liquid were calculated and compared. Table 4.9 presents the results that were obtained when sorption and solubility values were measured for the specimens that were soaked in distilled water and artificial saliva.

Table 4.9: Mean sorption and solubility values for specimens submersed in different liquids

	Distilled Water	Artificial Saliva
Solubility in µg/mm^3	0.1947	0.0911
Sorption in µg/mm^3	21.8672	21.7815

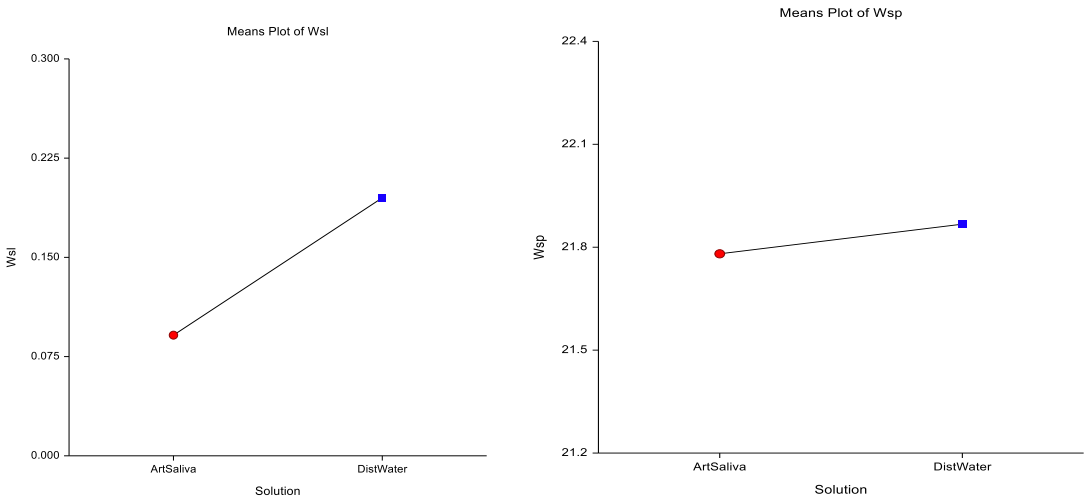

Figure 4.8: Mean sorption and solubility plot for specimens submersed in different liquids

4.8.1 Comparison of means for *"Distilled water"* and *"Artificial saliva"*

The specimens that were soaked in distilled water obtained mean Wsp and Wsl values of 21.8672 µg/mm^3 and 0.1947 µg/ mm^3 respectively (cf. Table 4.8). When these means are compared to the mean Wsp (21.7815 µg/mm^3) and Wsl (0.0911 µg/ mm^3) values obtained by the specimens that were soaked in artificial saliva (cf. Table 4.7), it emerges that the mean sorption and solubility values were lower for the heat-cured acrylic specimens that were soaked in artificial saliva than for the specimens that were soaked in distilled water.

4.9 ANOVA statistical analysis

The first analytical procedure was a one-way analysis of variance to determine whether a statistically significant difference ($\alpha = 0.05$) existed between the means of the Wsl and Wsp variables. The within-sample variances were analysed to see if they were equal and whether the data showed a normal distribution. For both variables, a significant difference in variance was identified (Wsl $p<0.001$; Wsp $p<0.001$), but no clear pattern emerged. The within-sample distributions were significantly non-normal (Wsl $p<0.001$; Wsp $p<0.001$), with Wsl having a negative value (-4.36, $p<0.001$), indicating a skewness to the left, and Wsp having a positive value (4.52, $p<0.001$), indicating a skewness to the right. For both the Wsl and Wsp variables, the test for "equal means allowing for unequal variances" was highly significant ($p<0.001$). The Tukey-Kramer multiple comparison test was used to indicate significant differences among the means of the different sample groups. The following significant differences were identified for Wsl and Wsp, respectively:

Table 4.10: Wsl results for Tukey-Kramer multiple comparison test

Group	Mean	Different from Groups
No Surface Treatment, Distilled Water (A)	0.1843	B and D
No Surface Treatment, Artificial Saliva (B)	0.0620	A, E and F
Mechanical Polishing, Distilled Water (C)	0.1593	D
Mechanical Polishing, Artificial Saliva (D)	0.0225	A, C, E and F
Light-Cured Varnish, Distilled Water (E)	0.2406	B and D
Light-Cured Varnish, Artificial Saliva (F)	0.1886	B and D

Table 4.11: Wsp results for Tukey-Kramer multiple comparison test

Group	Mean	Different from Groups
No Surface Treatment, Distilled Water (A)	22.3690	B, C, D, E and F
No Surface Treatment, Artificial Saliva (B)	21.7813	A
Mechanical Polishing, Distilled Water (C)	21.8613	A

Mechanical Polishing, Artificial Saliva (D)	21.8634	A
Light-Cured Varnish, Distilled Water (E)	21.3713	A
Light-Cured Varnish, Artificial Saliva (F)	21.6997	A

The results indicated that the “Mechanical polishing, soaked in artificial saliva” group exhibited significantly lower Wsl values than four out of the five groups. Only sample groups “No surface treatment, artificial saliva” and “Mechanical polishing, artificial saliva” exhibited statistically significant lower Wsl values than the control group. For Wsp, the sample group “No surface treatment, soaked in distilled water” (control) had a significantly higher mean value than any of the other five sample groups.

The second analysis performed was a Two-Way Analysis of Variance, with “Treatment” and “Solution” as effect variables. The aim of this analysis was to determine whether the “Treatment” and “Solution” effects made a significant difference among the Wsl and Wsp mean values obtained. The impact that the interaction between the “Treatment” and “Solution” effects had on the Wsl and Wsp mean values was analysed as well. The following significant differences were identified for Wsl and Wsp, respectively:

Table 4.12: Wsl results for "treatment" effect - Tukey-Kramer multiple comparison test

Group	Mean	Different from Groups
No Surface Treatment (1)	0.1231682	3
Mechanical Polishing (2)	0.09092386	3
Light-Cured Varnish (3)	0.2146183	1 and 2

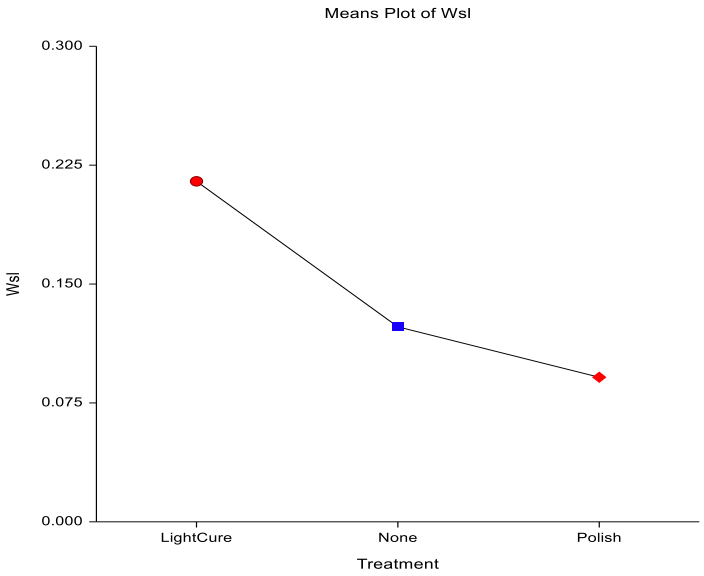

Figure 4.9: Means plot for Wsl indicating "treatment" effect

Table 4.13: Wsl results for "solution" effect - Tukey-Kramer multiple comparison test

Group	Mean	Different from Groups
Distilled Water (1)	0.1947414	2
Artificial Saliva (2)	0.09106553	1

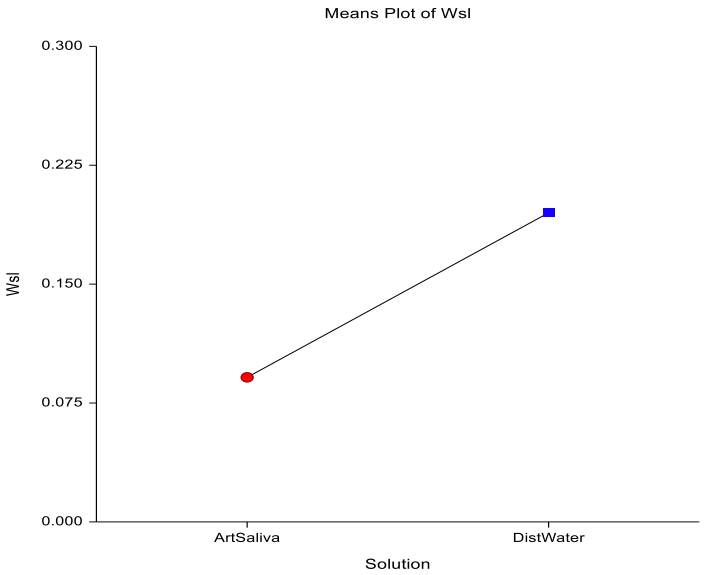

Figure 4.10: Means plot for Wsl indicating "solution" effect

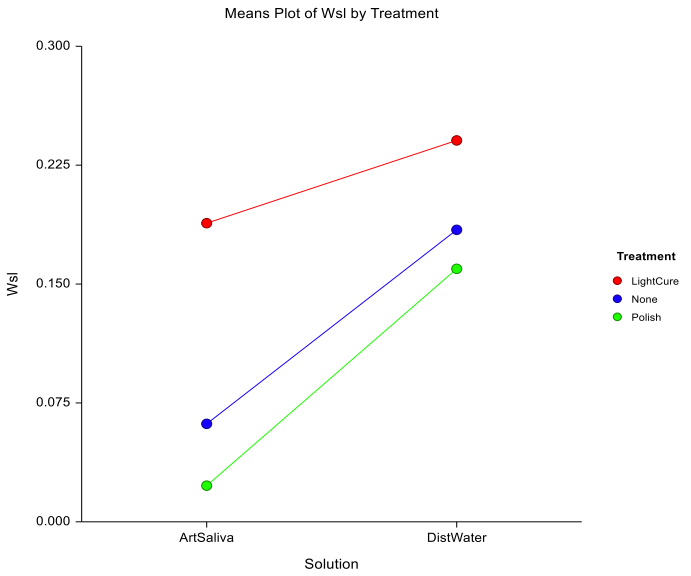

Figure 4.11: Means plot for Wsl indicating the "interaction" effect

For the Wsl variable, both the main effects proved to have a highly significant impact ($p<0.001$) on the mean Wsl values (cf. Table 4.11 and Figure 4.9) (cf. Table 4.12 and Figure 4.10), while the interaction component between "Treatment" and "Solution" had no significant effect as a whole ($p=0.18$) (cf. Table 4.9 and Figure 4.11).

Table 4.14*:* Wsp results for "treatment" effect – Tukey-Kramer multiple comparison test

Group	Mean	Different from Groups
No Surface Treatment (1)	22.07517	3
Mechanical Polishing (2)	21.86234	3
Light Cure Varnish (3)	21.5355	1 and 2

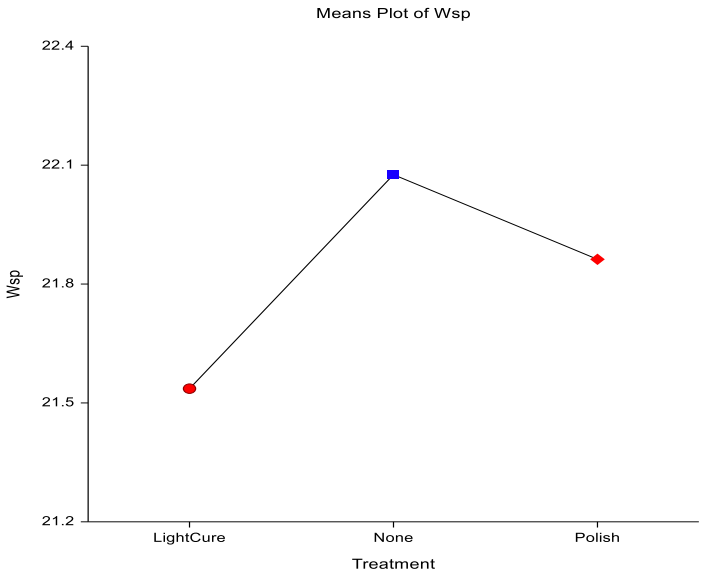

Figure 4.12: Means plot for Wsp indicating "treatment" effect

Table 4.15: Wsp results for "solution" effect – Tukey-Kramer multiple comparison test

Group	Mean	Different from Groups
Distilled Water (1)	21.86718	N/A
Artificial Saliva (2)	21.7815	N/A

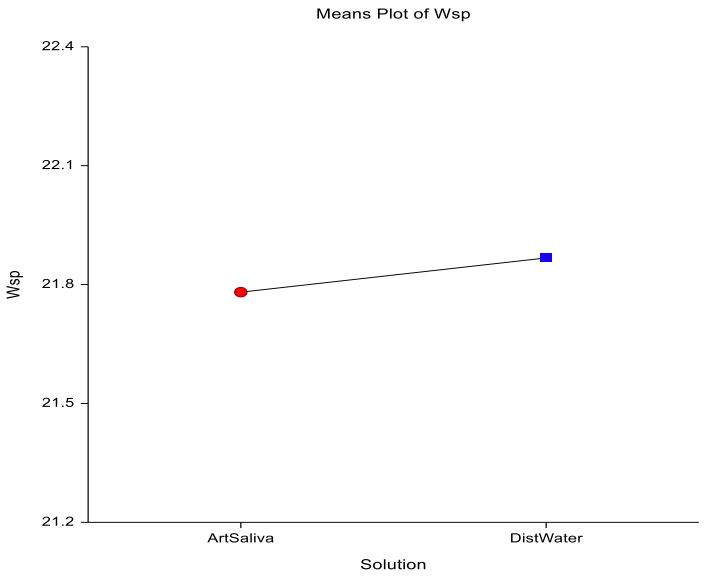

Figure 4.13: Means plot for Wsp indicating "solution" effect

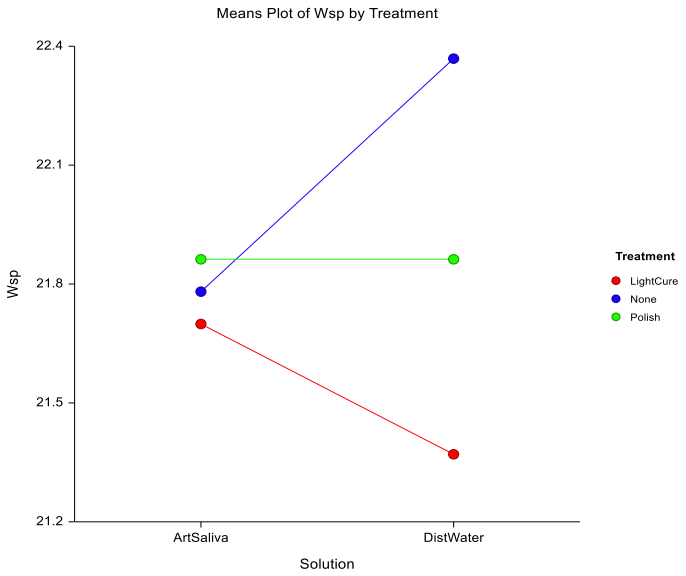

Figure 4.14: Means plot for Wsp indicating the "interaction" effect

For the Wsp variable, both "Treatment" (cf. Table 4.13 and Figure 4.12) and the interaction between the "Treatment" and "Solution" (cf. Table 4.10 and Figure 4.14) proved to have a highly significant effect ($p<0.001$) on the mean Wsp values, yet "Solution" as an individual effect resulted in no significant difference ($p=0.38$) (cf. Table 4.14 and Figure 4.13).

4.10 Conclusion

Chapter Four has provided a comprehensive analysis of the results of the data collected in the study. Descriptive statistics were used to summarise the data and possible associations between variable groups were determined with the use of inferential statistics. The results from the objectives were analysed and the hypotheses were accepted, rejected, or partially accepted in cases where variables did not have the same effect on both sorption and solubility values. The following findings were deemed noteworthy and of importance to the aim of the study:

1. Mechanical polishing proved to be the most effective surface treatment for reducing solubility in this study.
2. Light-cured varnish proved to be the most effective surface treatment for reducing sorption in this study.
3. The sorption and solubility values of heat-cured denture base material was lower when soaked in an artificial saliva solution, than in distilled water.

4. The sample group that exhibited the lowest statistically significant solubility values was the “Mechanical polishing, soaked in artificial saliva” group.
5. The sample group that exhibited the highest statistically significant sorption values was “No surface treatment, soaked in distilled water” group.
6. Both “Surface treatments” and “Solutions” proved to have a statistically significant effect on the solubility values evinced by heat-activated denture base material.
7. Both “Surface treatments” and the interaction between the “Surface treatment” and “Solution” variables proved to have a statistically significant effect on the sorption values of heat-activated denture base material.

Chapter Five will provide an in-depth discussion of the results obtained and make inferences from and suggest reasons for the occurrences recorded in the study.

Chapter 5

DISCUSSION

5.1 Introduction

The effects of sorption and solubility on the properties of denture base acrylics have previously been investigated with the overall goal of finding ways to preserve the properties of the material and prolong the longevity of a dental prosthesis. In an attempt to reduce the sorption and solubility experienced by denture base materials, it was decided to evaluate the effect that surface treatments had on the sorption and solubility values experienced by Vertex™ *Rapid Simplified* type-one, class-one denture base material. Specifically, these treatments took the form of mechanical polishing and the application of *Optiglaze*™ light-cured varnish, before the material was soaked in artificial saliva or distilled water. This study used the formulae provided by ISO 20795-1: 2013 (E) to test for sorption and solubility (see Section 3.7.4) and recorded the data in a custom-designed Microsoft Excel™ spreadsheet (see Appendix B). The data was analysed with the NCSS statistical package (NCSS 2019 Statistical Software, 2019). This chapter provides a detailed discussion of the results presented in Chapter 4 in tandem with the research objectives and hypotheses, in sequential order. Associations between the results of this study and of other research in the same field are identified, the findings are appraised and possible explanations for the observed effects are advanced.

5.2 ISO sorption and solubility testing

The specimen fabrication and experimentation were conducted in strict accordance with ISO 20795-1: 2013 (E) to test for sorption and solubility of heat-cured PMMA material, with the exception of the design of the two-part mould (see Appendix D). The portion of the mould housing the specimen was in accordance with the dimensions prescribed by ISO 20795-1: 2013 (E) to test for sorption and solubility of heat-cured PMMA material, but the aligning mechanism of the two parts was modified to ensure optimum accuracy of the specimens produced. Various authors such as Tuna et al. (2008:191–197), Engelbrecht (2010), Al-Muthaffar (2016:481– 488) and Saini et al. (2016:288) have conducted research pertaining to the sorption and solubility of denture base acrylic, but their specimen dimensions and methodology varied from that used in this study and prescribed by ISO. Because there appears to be little consistency in the variables evaluated, it is difficult to make direct comparisons among the findings of these authors.

All the materials in this study were handled, used, and stored as recommended by the manufacturer. Each variable group was fabricated and tested individually to isolate the data set, preventing it from being skewed by the possible influence of the variables from other sample groups. All the sample groups reached a constant mass (m_1) on the second day of

their conditioning process, after which they were immersed in distilled water (sample groups A, C and E) or artificial saliva (sample groups B, D and F) for a seven-day period to record their saturated mass (m_2). The specimens had to be reconditioned to a constant mass (m_3), which they all reached on the 11th day of their respective conditioning processes, with the exception of groups B and D. Groups B and D took a day longer to reach constant mass m_3, taking a total of 12 days to complete the testing procedure recommended by ISO 20795-1: 2013 (E) to test for sorption and solubility of heat-cured PMMA material. The time taken to complete the sorption and solubility test per sample group (Table 4.1) was considerably shorter than the time frame recorded by Engelbrecht (2010), who required a total of 54 days for the completion of the test. The study by Engelbrecht (2010) also found that the specimens did not all reach constant mass m_1 and m_3 on the same day, with the first specimen reaching m_1 on day 8 and the last specimen on day 15. Similar time frames were observed with the recording of constant mass m_3. These variances were attributed to the thickness of the specimens, which were increased to 2mm from the 0.5mm specified by ISO. These observations may indicate that the thickness of the specimens directly affects the time required for the specimens fabricated for sorption and solubility testing to reach a constant mass. The data recorded in this study indicated that the medium in which the specimens were immersed may also affect the time required for specimens to reach a constant mass. Two of the three sample groups (B and E) soaked in artificial saliva took a day longer to reach constant mass m_3 in comparison to the other groups in this study soaked in distilled water (Table 4.1). This increase in time to reach a constant mass after saturation may be due to the higher viscosity of the artificial saliva solution, which reduces the diffusion coefficient of the medium (Dickson, 2020).

5.3 To determine the sorption and solubility of heat-cured acrylic with no surface treatment soaked in distilled water or artificial saliva

Objectives One and Two: Hypothesis One

Objective one was to record baseline sorption and solubility values to assess the effectiveness of surface treatments and artificial saliva on reducing the levels of sorption and solubility observed in Vertex™ *Rapid Simplified* denture base material. To accept or reject hypothesis one, it was necessary to compare the sorption and solubility results of the specimens with no surface treatment soaked in distilled water with those soaked in artificial saliva. The specimens in sample group A obtained a mean sorption value of 22.3690 µg/mm^3, and a mean solubility value of 0.1843 µg/mm^3 (Table 4.2), which are both within the parameters set out by ISO 20795-1: 2013 (E) for a type-one polymer. A single specimen in the group recorded a negative solubility value of -0.1891 µg/mm^3 (Table 4.2) which indicated that it was not able to expel all the moisture it adsorbed during the saturation process.

Negative solubility values were also recorded by Tuna et al. (2008), who suggested that the material or content within the material was responsible for bonding with the water molecules chemically. Due to the sensitivity of the scale, the possibility also exists that this negative value was a result of human error. The specimen could have been insufficiently dried after removal from the distilled water or a foreign body might have been attached to its surface, resulting in an increase in mass. It was decided to keep this value in the recorded data as it is believed that the variance is not of such an extent as to affect the conclusions drawn from the study and might well occur in the implementation of these treatments in real-life situations. The sorption values recorded for this sample group were similar to those recorded by Engelbrecht (2010), who also had an unpolished sample group soaked in distilled water fabricated from Vertex™ *Rapid Simplified* denture base material. The author recorded a mean sorption value of 23 µg/mm^3 for the sample group that received no surface treatment, soaked in distilled water. The solubility value recorded was however considerably higher, with a mean value of 1.1 µg/mm^3. It is possible that the higher solubility value recorded is because of the thicker specimens and a different fabrication method from that used by Engelbrecht (2010).

Objective two was to determine the effect of no surface treatment on the sorption and solubility of Vertex™ *Rapid Simplified* denture base material soaked in artificial saliva. The specimens in sample group B obtained a mean sorption value of 21.7813 µg/mm^3, and a mean solubility value of 0.0620 µg/mm^3 (Table 4.3), which are both within the parameters set out by ISO 20795-1: 2013 (E) for a type-one polymer. Four specimens in sample group B recorded negative solubility values. These values were only very slightly negative, with the average for the four values being -0,04158 µg/mm^3. To put this into perspective, the values recorded for these specimens at m_3 were on average 0.000037g heavier than what they were when recorded at m_1. This trend, where minute negative solubility values were recorded, was observed in both “no surface treatment” (sample group B) and “mechanical polishing” (sample group D) groups soaked in artificial saliva. It is possible that these occurrences for specimens soaked in artificial saliva may be due to the variation in molecular structure or lower diffusion coefficient of the artificial saliva solution as opposed to that of distilled water (Dickson, 2020; Arima et al., 1996:480; Van der Bijl & de Waal, 1994:299–303). These factors may affect the rate at which solubility takes place, as both sample groups B and D took a day longer to reach constant mass m_3 than the other sample groups in the study. If the specimens that recorded negative solubility values had been conditioned for another day, the possibility exists that they would have recorded a positive solubility value. This however would have deviated from the ISO protocol, which states that a specimen has reached a conditioned weight when the difference between two successive weighing procedures is less than 0.2mg.

As a result of these findings, the null hypothesis relating to objectives one and two was accepted, as the specimens that were soaked in artificial saliva recorded lower mean sorption and solubility values than the sample group which received no surface treatment, soaked in distilled water. The Tukey-Kramer Multiple Comparison Test indicated that the lower sorption and solubility values recorded by the specimens that received no surface treatment and soaked in artificial saliva were statistically significant (Table 4.9 and Table 4.10). These findings partially correlate with those of Saini et al. (2016:288). Saini et al. compared the sorption and solubility of heat- and self-cured acrylic resins soaked in different solutions. The solutions included distilled water, artificial saliva, denture cleansing solution, a mixture of distilled water and denture cleaning solution and a mixture of artificial saliva and denture cleaning solution. The statistical analysis indicated that the type of material, time, and solution of storage significantly affected the water sorption and solubility values recorded ($P < 0.001$).

For both heat- and self-cured materials the least sorption was observed when the specimens were soaked in artificial saliva, with mean water sorption values varying from 17.5 ± 0.88 to 27.25 ± 1.04 μg/mm^3 for heat cured and from 12.75 ± 0.55 to 19.75 ± 1.04 μg/mm^3 for self-cured. Artificial saliva did not however have the same effect on the solubility of the heat- and self-cured materials, as the lowest solubility levels were recorded for the specimens soaked in distilled water, with mean solubility levels varying from 0.25 ± 0.55 to 1.5 ± 0.55 μg/mm^3 for heat cured and from 1.5 ± 0.55 to 6.5 ± 0.55 μg/mm^3 for self-cured. Observations arising from the present study are in agreement with Saini et al. (2016:288), who concluded that the molecular composition of the liquid in which the specimens are submersed affects the levels of sorption and solubility recorded. Noteworthy comparisons between this study and that of Saini et al. (2016: 288) can however not be drawn as the study by Saini et al. (2016: 288) did not follow ISO 20795-1: 2013 (E) recommendations to test for sorption and solubility of a type-one polymer.

Braden et al. (1976:730–732); Kalachandra & Turner (1987:329–338) and Sideridou et al. (2004:367376) all indicated that water sorption and solubility may follow Fick's law of diffusion. A review of the literature regarding the principles of diffusion suggests that factors such as the concentration gradient and diffusion coefficient between the material and the liquid in which it is submersed may affect the levels of sorption and solubility recorded. The difference in molecular composition between the two solutions may result in different concentration gradients, altering the tendency for molecules to diffuse between the material and the medium. The diffusion coefficient may also affect the phenomena of sorption and solubility as it indicates the rate at which diffusion takes place. The diffusion coefficient is influenced by the

temperature of the system and the viscosity of the medium (Dickson, 2020). The temperature remained constant throughout the testing procedure in this study, but the artificial saliva solution used had a much higher viscosity than that of the distilled water. It is therefore possible that a lower diffusion coefficient also contributed to the lower sorption and solubility values recorded.

In summary, soaking the specimens that received no surface treatment in artificial saliva significantly reduced both the sorption and solubility levels observed in comparison to the specimens that were soaked in distilled water. It can therefore be assumed that soaking a prosthesis fabricated from Vertex™ *Rapid Simplified* denture base material with no surface treatment in artificial saliva will result in significantly lower sorption and solubility values than would occur were it to be soaked in distilled water.

5.4 To determine the sorption and solubility of mechanically-polished, heat-cured acrylic soaked in distilled water or artificial saliva

Objectives three and four: Hypotheses two and three

Objective three was established in order to determine the effect of mechanical polishing on the sorption and solubility of Vertex™ *Rapid Simplified* denture base material soaked in distilled water. To accept or reject hypothesis two, it was necessary to compare the sorption and solubility results of the specimens that were mechanically polished and soaked in distilled water to those that received no surface treatment soaked in distilled water. The specimens in sample group C obtained a mean sorption value of 21.8613 µg/mm^3, and a mean solubility value of 0.1593 µg/mm^3 (Table 4.3), which are both within the parameters set out by ISO 20795-1: 2013 (E) for a type-one polymer. The null hypothesis relating to objective three was rejected, as the specimens that were mechanically polished recorded lower mean sorption and solubility values than the sample group which received no surface treatment, soaked in distilled water. The Tukey-Kramer Multiple Comparison Test indicated that the lower sorption values recorded by the mechanically-polished specimens soaked in distilled water were statistically significant. Even though mechanical polishing reduced the solubility values, it was not deemed statistically significant (cf. Table 4.9 and Table 4.10).

These findings are in line with those of Engelbrecht (2010) and Al-Muthaffar (2016:484), who also found that surface treatment in the form of mechanical polishing was successful in reducing the mean sorption and solubility values experienced by heat-cured denture base material. Al-Muthaffar (2016:481–488) tested the effect of a conventional polishing procedure on the sorption of heat- and cold-cured denture base material and found that the conventional

polishing procedure significantly reduced the amount of sorption experienced by the materials. Engelbrecht (2010) recorded similar results, with the conventional polishing procedure reducing both mean sorption and solubility values of the heat-cured denture base material, although only the reduction in sorption was deemed significant. The mechanical polishing of denture base material is associated with high levels of friction which generates a considerable amount of heat within the material. As the heat generated is of a greater temperature than the flashpoint of methyl methacrylate monomer, it was thought that the heat generated during the mechanical polishing procedure may serve to reduce the amount of residual monomer within the specimen, resulting in lower solubility levels. This theory was tested by Vallittu (1996:188–192), who also thought that the generation of heat within the specimen during the mechanical polishing procedure was responsible for the lesser release of monomer from the denture base material. To test this, the temperature of the specimens was recorded during the polishing procedure, and the monomer content was measured afterwards. The results indicated that the temperature of the specimen increased, but there was no significant reduction of residual monomer levels after the polishing procedure (Vallittu, 1996:191). Significant increases in specimen temperature were noticed during the mechanical polishing procedure in this study. To prevent warping or damage to the specimens, they were all double stacked with an additional specimen to provide extra support and heat dispersion.

The findings of Vallittu (1996:188–192) were subjectively reviewed together with literature on the chemical properties of methyl methacrylate, and assessed in conjunction with the findings of this study. The temperature generated during the polishing procedure exceeds the flashpoint of methyl methacrylate. Theoretically speaking, the heat exposure during the mechanical polishing procedure should reduce the amount of residual monomer present in the specimen, even if it is on a minute scale. Noticeable differences in specimen size between this study and that by Vallittu (1996:188–192) were identified, with the specimens used by Vallittu (1996:188–192) being six times thicker than the specimens used in this study. The possibility exists that the increase in temperature during the polishing procedure has a much greater effect on the thinner, smaller specimens used in this study.

Al-Muthaffar (2016:486) explains that the increase in temperature during the polishing procedure may also exceed the glass transition temperature of the material, resulting in the smearing of the material's surface. The smeared surface is thought to decrease the surface polarity of the material, and effectively reduces the concentration of polar sites for water molecules to form hydrogen bonds with. As the resin's polarity is one of the main factors governing the uptake of water into the structure of denture base acrylics, the reduction in the concentration of polar sites on denture base acrylics may reduce the rate of sorption observed in the material (Malacarne et al., 2006:978). It is therefore possible that the generation of heat

and the smearing of the specimens' surface during the polishing procedure contribute to the positive effect mechanical polishing has on the sorption and solubility of heat-cured denture base material. The extent of this is however unknown and more tests would need to be conducted to determine the exact effects that the heat generated during the polishing procedure has on the sorption and solubility of the material. There is also the possibility that the surface roughness of denture base materials may affect their sorption and solubility. Rough surfaces essentially have a larger surface area, which increases the contact interface between the water molecules and the surface of the denture base. According to Vallittu (1996:191), a diminished diffusion surface may lead to a reduction in the release of monomer from denture base materials. Similar findings were recorded by Al-Muthaffar (2016:481–488), who noted that the surface finish of the denture base material may have affected the levels of sorption observed. The phenomenon is also explicable in terms of contact angle hysteresis. A study published by Rahal et al. (2004b:225–230) investigated the influence of chemical and mechanical polishing on the water sorption and solubility of denture base acrylic resins. The authors noted that reducing the surface roughness of the material not only results in a smaller surface area but may also affect the hydrophilic nature of the material (Rahal et al., 2004:228). Monse´ne´go et al. (1989:308–312) suggest that water droplets form lower contact angles with rougher surfaces. Surfaces that produce lower contact angles are of a more hydrophilic nature, increasing the material's affinity to water.

Objective four was established to determine the effect of mechanical polishing on the sorption and solubility of Vertex™ *Rapid Simplified* denture base material soaked in artificial saliva. To accept or reject hypothesis three, it was necessary to compare the sorption and solubility results of the specimens that were mechanically polished and soaked in artificial saliva to those that received no surface treatment soaked in artificial saliva. The specimens in sample group D obtained a mean sorption value of 21.8634 µg/mm^3, and a mean solubility value of 0,0225 µg/mm^3 (Table 4.4), which are both within the parameters set out by ISO 20795-1: 2013 (E) for a type-one polymer. As with sample group B, sample group D recorded six specimens with negative solubility values. These values were very slightly negative, with the average for the six values being -0.0319 µg/mm^3. In perspective, this meant that the values recorded for these specimens at m_3 were on average 0.000028g heavier than what they were when they were recorded at m_1. It is speculated that these occurrences for specimens soaked in artificial saliva might be due to the variation in molecular structure or lower diffusion coefficient of the artificial saliva solution as opposed to that of distilled water (Dickson, 2020; Arima et al., 1996:480; Van der Bijl & de Waal, 1994:299–203). These factors may affect the rate at which solubility takes place, as sample group D took a day longer to reach constant mass m_3 than the sample groups soaked in distilled water. If the specimens that recorded negative solubility values were

conditioned for an additional day, it is possible that they might have recorded a positive solubility value. But this would have represented a departure from ISO protocol, which states that a specimen has reached a conditioned weight when the difference between two successive weighing procedures is less than 0.2mg.

The results indicate that the mean solubility value was lower and the mean sorption value was higher for heat-cured acrylic specimens that were mechanically polished and soaked in artificial saliva, as opposed to the specimens that received no surface treatment soaked in artificial saliva. The null hypothesis relating to objective four was therefore partially accepted, as the specimens that were mechanically polished only recorded lower solubility values than the specimens that received no surface treatment soaked in artificial saliva. The Tukey-Kramer Multiple Comparison Test indicated that neither the sorption nor the solubility values recorded by the mechanically polished specimens soaked in artificial saliva were statistically significant in comparison to the specimens that received no surface treatment, soaked in artificial saliva.

Mechanical polishing thus had the same positive effect on the solubility of the specimens that were soaked in artificial saliva as it had on the specimens that were soaked in distilled water. But as was the case with distilled water, this effect was deemed not statistically significant by means of the ANOVA test. The observed reduction in solubility levels may be due to the diminished surface area of the polished specimens and their exposure to heat during the polishing procedure, which may reduce the residual monomer within the specimens (Al-Muthaffar, 2016:486; Vallittu, 1996:191). Objective two established the positive effect of artificial saliva as a sole variable on the sorption and solubility of Vertex™ *Rapid Simplified* denture base material, as it reduced both the sorption and solubility values of the sample group B in comparison to those of sample group A (Table 4.9 and Table 4.10). The same effect was not observed for objective four, however, as the interaction effect between mechanical polishing and artificial saliva only reduced the solubility of the specimens. The precise reason for this occurrence is unknown, though a possible cause has been suggested by Al-Muthaffar (2016:486–487). According to the safety data sheet (MSDS ID: MPO201300UK) for Vertex™ *Polish Paste Beige* (Vertex Dental, 2019), the polishing paste consists of paraffin, aluminium oxide and fatty acids. It was suggested by Al-Muthaffar (2016:486) that when the mechanically polished specimens were soaked in distilled water, the decrease in sorption could be attributed to the smeared surfaces of the specimens decreasing the surface polarity of the material, effectively reducing the concentration of polar sites where water molecules could form hydrogen bonds. One possibility for the observed increase in sorption for the mechanically polished specimens soaked in artificial saliva is that the interaction between the constituents

of the polishing paste and that of artificial saliva affects the affinity between the specimens and the molecules in the solution, resulting in an increase in sorption.

The Tukey-Kramer Multiple Comparison Test deemed there to be no significant difference in sorption values between any of the sample groups in this study, with the exception of group A, which exhibited significantly higher sorption values than any other group. Because the differences in sorption values between the sample groups were so minute, it is difficult to make accurate assumptions as to why certain events occurred in the phenomenon of sorption.

In summary, mechanical polishing reduced the solubility levels of the material in both distilled water and artificial saliva when compared with the specimens that received no surface treatment. Although these reductions were not deemed statistically significant, it can be assumed that mechanical polishing will have a positive effect on the properties of Vertex™ *Rapid Simplified* denture base material affected by solubility. The sorption values were only reduced in the sample group that received mechanical polishing soaked in distilled water. Mechanical polishing was deemed to significantly reduce the sorption values of the specimens soaked in distilled water, but due to the minute differences in sorption values, it can be assumed that mechanical polishing will not have an effect that is clinically significant on the properties of Vertex™ *Rapid Simplified* denture base materials affected by sorption.

5.5 To determine the sorption and solubility of heat-cured acrylic treated with a light-cured varnish soaked in distilled water or artificial saliva

Objectives five and six: Hypotheses four and five

Objective five was established to determine the effect of a light-cured varnish on the sorption and solubility of Vertex™ *Rapid Simplified* denture base material soaked in distilled water. To accept or reject hypothesis five, it was necessary to compare the sorption and solubility results of the specimens that were treated with an *Optiglaze*™ light-cured varnish soaked in distilled water with those that received no surface treatment soaked in distilled water. The specimens in sample group E obtained a mean sorption value of 21.3713 µg/mm^3, and a mean solubility value of 0.2406 µg/mm^3 (Table 4.5), which are both within the parameters set out by ISO 20795-1: 2013 (E) for a type-one polymer. The results indicated that the mean sorption value was lower and the mean solubility value was higher for heat-cured acrylic specimens that were treated with the light-cured varnish and soaked in distilled water, than for the specimens that received no surface treatment soaked in distilled water. The null hypothesis relating to objective five was therefore partially accepted, as the specimens that were treated with the

light-cured varnish only recorded lower sorption values than the specimens which received no surface treatment soaked in distilled water. The Tukey-Kramer Multiple Comparison Test indicated that the lower sorption values recorded by the specimens that were treated with the light-cured varnish soaked in distilled water were statistically significant. Even though the light-cured varnish increased the solubility values observed in Vertex™ *Rapid Simplified* denture base material, this was deemed not to be of statistical significance (Table 4.9 and Table 4.10).

These findings indicate that the application of *Optiglaze*™ light-cured varnish increased the observed levels of solubility. The increase in solubility may perhaps be attributed to the composition of *Optiglaze*™ light-cured varnish. According to the safety data sheet, *Optiglaze*™ *Glossy, Protective Agent* consists of 25-50% methyl methacrylate (GC America, 2020). This additional methyl methacrylate present on the specimens may therefore be responsible for the elevated solubility levels, as suggested by published literature (Kedjarune et al., 1999:25–30; Kostić et al., 2020:254–263; Tuna et al., 2008:191–197). The application of *Optiglaze*™ had a positive result on the sorption of Vertex™ *Rapid Simplified* denture base material soaked in distilled water. A possible explanation for this occurrence may be that the application *Optiglaze*™ alters the polarity of the specimen's surface. As explained by Malacarne et al. (2006:978), the resin's polarity is one of the main factors governing the uptake of water into the structure of denture base acrylics, and a reduction in the concentration of polar sites may reduce the rate of sorption observed. A systematic review of the literature canvassed in Ferracane (2006:211–222), together with the product information supplied by GC America (2020), indicates that *Optiglaze*™ may act as a surface sealer, sealing microscopic cracks, pores and irregularities on the surface of the specimens. It has been suggested that water molecules are adsorbed to the surface of the material and are further absorbed into the body of the denture base through porosity and intermolecular spaces via diffusion (Ferracane, 2006:214; Sakaguchi & Powers, 2012:51–52). If the quantity of irregularities on the surface is reduced by the application of *Optiglaze*™*,* this may inhibit the uptake of water into the body of the material.

Objective six was established to determine the effect of a light-cured varnish on the sorption and solubility of Vertex™ *Rapid Simplified* denture base material soaked in artificial saliva. To accept or reject hypothesis six, it was necessary to compare sorption and solubility results for the specimens that were treated with *Optiglaze* light-cured varnish soaked in artificial saliva with those of the specimens that received no surface treatment soaked in artificial saliva. The specimens in sample group F obtained a mean sorption value of 21.6997 µg/mm^3, and a mean solubility value of 0.1886 µg/mm^3 (Table 4.6), which are both within the parameters set out by ISO 20795-1: 2013 (E) for a type-one polymer. The results indicated that the mean sorption value was lower and the mean solubility value was higher for heat-cured acrylic specimens

that were treated with the light-cured varnish and soaked in artificial saliva, compared with the specimens that received no surface treatment soaked in artificial saliva. The null hypothesis relating to objective six was therefore partially accepted as the specimens that were treated with the light-cured varnish recorded only lower sorption values than the specimens that received no surface treatment soaked in artificial saliva. The Tukey-Kramer Multiple Comparison Test indicated that the higher solubility values recorded by the specimens that were treated with the light-cured varnish and soaked in artificial saliva were statistically significant. On the other hand, even though the light-cured varnish reduced the sorption values observed in *Vertex™ Rapid Simplified* denture base material, it was deemed not to be statistically significant (Table 4.9 and Table 4.10).

No similar studies investigating the interaction effect between artificial saliva and light-cured varnish on the sorption and solubility of denture base materials could be identified following a thorough review of the literature. This study found that the application of *Optiglaze™* had the same positive effect on the sorption of the specimens soaked in artificial saliva as it had on the specimens soaked in distilled water. But unlike the case of distilled water, this effect was deemed not statistically significant by means of the ANOVA test. As with sample group E, it can again be proposed that this observed reduction in sorption levels may be due to a change in polarity and the sealing of irregularities on the surfaces of the specimens due to the application of *Optiglaze™*. The fact that the specimens in sample group F were submersed in artificial saliva means that the effect this may have had on sorption also needs to be considered. It is possible that both the diffusion coefficient and the concentration gradient between the specimen and the solution may impact the extent of diffusion taking place. As the artificial saliva solution has a higher viscosity than distilled water, as well as a different molecular composition, it is possible that the reduction in sorption that was observed may have been impacted by the diffusion coefficient and concentration gradient discrepancies between the specimens and the solution. As with sample group E, the application of *Optiglaze™* resulted in an increase in the solubility levels recorded. This increase was deemed statistically significant and is again credited to the composition of *Optiglaze™*, which consists of 25–50% methyl methacrylate.

In summary, the application of *Optiglaze™* reduced the sorption levels of specimens in both distilled water and artificial saliva compared to specimens that received no surface treatment, but only the specimens that were soaked in distilled water were deemed to have a significant reduction. It can therefore be assumed that the application of *Optiglaze™* will reduce the extent of sorption experienced by prostheses fabricated from Vertex™ *Rapid Simplified* denture base material soaked in artificial saliva or distilled water. The same positive effects that *Optiglaze™* had on the sorption of Vertex™ *Rapid Simplified* denture base material was not, however,

observed for solubility. The application of *Optiglaze*™ increased the solubility in both sample groups E and F, with the increase evinced by the specimens soaked in artificial saliva deemed to be statistically significant. It can therefore be assumed that the application of *Optiglaze*™ to prostheses fabricated from Vertex™ *Rapid Simplified* denture base material will result in an increase in solubility when the prostheses are soaked in distilled water or artificial saliva.

5.6 To determine which surface treatment results in the least sorption and solubility of the material

Objective seven – Hypothesis six

Objective seven was established to determine which surface treatment results in the least sorption and solubility of the *Vertex*™ *Rapid Simplified* denture base material. To accept or reject hypothesis six, it was necessary to compare the sorption and solubility results of the specimens that were treated with *Optiglaze*™ light-cured varnish with the results of those that were mechanically polished. The specimens that were treated with *Optiglaze*™ light-cured varnish recorded a mean sorption value of 21.5355 µg/mm^3, and a mean solubility value of 0.2146 µg/mm^3 (Table 4.7). The specimens that were mechanically polished recorded a mean sorption value of 21.8624 µg/mm^3, and a mean solubility value of 0.0909 µg/mm^3 (cf. Table 4.7). The application of both surface treatments resulted in sorption and solubility values that are within the parameters set out by ISO 20795-1: 2013 (E) for a type-one polymer. The results indicate that the mean sorption value was lower, and the mean solubility value higher, for heat-cured acrylic specimens that were treated with the light-cured varnish than was the case with the specimens that were mechanically polished. The null hypothesis relating to objective seven is therefore partially accepted, as only the specimens that were mechanically polished recorded lower solubility values than the specimens that were treated with the light-cured varnish. The Tukey-Kramer Multiple Comparison Test indicated that both the lower sorption and higher solubility values recorded by the specimens that were treated with *Optiglaze*™ were statistically significant in comparison with the values for the specimens that were mechanically polished (Table 4.11 and Table 4.13).

Various studies have indicated that surface treatments in the form of mechanical polishing and the application of light-cured varnishes may have positive effects on the sorption or solubility of denture base materials (Szabó et al., 1985:249–256; Vallittu, 1996:188–192; Engelbrecht, 2010; Rahal et al., 2004b:225–230; Al-Muthaffar, 2016:481–488). Similar results were observed in this study, with both surface treatments proving to be successful in reducing either the sorption or solubility levels of the specimens to which they were applied. Findings from previous studies have indicated that the observed reductions may be the result of a variety of

factors including, but not limited to, a diminished diffusion surface, exposure to heat during the mechanical polishing procedure, alteration in polarity on the surface of the material and surface sealants acting as a physical barrier.

Analysis of the results recorded in this study indicates that mechanical polishing is the most effective surface treatment technique when attempting to reduce the levels of both sorption and solubility experienced by denture base materials. But even though mechanical polishing reduced both the sorption and solubility values of the specimens, the reduction in comparison to the control group was not deemed significant. It can therefore be assumed that the mechanical polishing of Vertex™ *Rapid Simplified* denture base material will not have an effect that is clinically significant on the properties of Vertex™ *Rapid Simplified* denture base materials affected by sorption and solubility.

5.7 To determine which medium results in the least sorption and solubility of the material

Objective eight – Hypothesis seven

Objective eight was established to determine which medium results in the least sorption and solubility of Vertex™ *Rapid Simplified* denture base material. To accept or reject hypothesis seven, it was necessary to compare the sorption and solubility results of specimens soaked in distilled water to those of specimens soaked in artificial saliva. The specimens that were soaked in distilled water recorded a mean sorption value of 21.8672 µg/mm^3, and a mean solubility value of 0.1947 µg/mm^3 (Table 4.8). The specimens that were soaked in artificial saliva recorded a mean sorption value of 21.7815 µg/mm^3, and a mean solubility value of 0.0911 µg/mm^3 (Table 4.8). The sorption and solubility values recorded in both mediums are within the parameters set out by ISO 20795-1: 2013 (E) for a type-one polymer. The null hypothesis relating to objective eight is therefore accepted. The Tukey-Kramer Multiple Comparison Test indicated that the lower solubility values recorded by the specimens that were soaked in artificial saliva were statistically significant in comparison to the values of the specimens that were soaked in distilled water. Although the specimens soaked in artificial saliva also recorded lower mean sorption values, the reduction was not deemed significant (Table 4.12 and Table 4.14).

Studies relating to the sorption and solubility of denture base materials submersed in different solutions have indicated that the phenomenon of sorption and solubility may be influenced by the molecular composition of the liquid in which the material is immersed (Saini et al., 2016:288; Zidan et al., 2020:3732). The results emerging from this study also indicate that the levels of sorption and solubility observed in denture base materials may be influenced by the

molecular composition of the liquid in which the material is submersed: the specimens that were soaked in artificial saliva recorded lower sorption and solubility values than the specimens that were soaked in distilled water. Research has suggested that the diffusion taking place in polymers follows Fick's Law of diffusion, so it is possible that the reduced uptake and release of substances from the specimens soaked in artificial saliva result from the principles governing the rate and extent of diffusion (Braden et al., 1976:730–732; Kalachandra & Turner, 1987:329–338; Sideridou et al., 2004:367–376; Ferracane, 2006:211–222).

A review of the results produced by this study indicates that an artificial saliva solution is the medium that results in the least sorption and solubility of Vertex™ *Rapid Simplified* denture base material. Even though soaking the specimens in artificial saliva reduced their sorption and solubility values in comparison to those soaked in distilled water, only the reduction in solubility was deemed significant. It can therefore be assumed that soaking prostheses fabricated from Vertex™ *Rapid Simplified* denture base material in artificial saliva overnight will reduce the amount of sorption and significantly reduce the amount of solubility taking place.

5.8 Conclusion

This chapter has provided an in-depth discussion of the results, observations and trends identified in this study. The findings were critically appraised in the light of relevant literature in the same field and possible reasons for the observed results were identified. The effects of the variables were discussed as individual events, as were the interactive components between variables. The chapter concludes with the finding that mechanical polishing and artificial saliva are the surface treatment and submersive medium, respectively, that produce the least sorption and solubility of Vertex™ *Rapid Simplified* denture base material. Chapter Six will offer a conclusion to the study, identifying its limitations and making recommendations.

Chapter 6

CONCLUSION

6.1 Introduction

This chapter offers an overview of the research and identifies its key findings. It provides a synopsis of the study's aim and individual objectives, plus a summary of its limitations. The contribution of the study to its field of research is highlighted, and recommendations are made for possible future research. Some concluding remarks wrap up the chapter.

6.2 Overview

The aim of this study was to compare the sorption and solubility rates of surface-treated heat-cured acrylic specimens with those of untreated acrylic specimens, soaked in distilled water and artificial saliva. More specifically, this study investigated whether surface treatments in the form of mechanical polishing or the application of *Optiglaze*™ light-cured varnish could reduce the amount of sorption and solubility that occur in Vertex™ *Rapid Simplified* heat-cured denture base material. The possibility that the rate of sorption and solubility of PMMA denture base material might be affected by the molecular structure of the medium in which it is immersed was also considered. It was of crucial importance for the study to produce standardised results that might be used as a benchmark for future research. This was done by strictly adhering to all ISO requirements through every step of the research process.

6.3 Conclusions

From statistical analysis of the results of the study, the following conclusions may be drawn in terms of its overall aim and specific objectives:

6.3.1 Overall aim

The results indicated that both surface treatments, and the composition of the medium in which the specimens were submersed, were successful in reducing either the sorption or solubility level recorded by the specimens. The analysis of the results suggests that overall, mechanical polishing was the most effective surface treatment procedure and that artificial saliva was the medium in which the specimens recorded the lowest sorption and solubility values.

6.3.2 Objectives

Objectives one and two were established to determine the sorption and solubility of heat-cured acrylic with no surface treatment soaked in distilled water and artificial saliva. The specimens soaked in artificial saliva recorded lower sorption and solubility values than the specimens soaked in distilled water. The reductions in both sorption and solubility were deemed to be statistically significant. The null hypothesis relating to objectives one and two was therefore accepted.

Objective three was established to determine the effect of mechanical polishing on the sorption and solubility of heat-cured acrylic soaked in distilled water. The specimens that were mechanically polished and soaked in distilled water recorded lower mean sorption and solubility values than the sample group which received no surface treatment, soaked in distilled water. Only the reduction in sorption was deemed to be statistically significant. The null hypothesis relating to objective three was therefore rejected.

Objective four was established to determine the effect of mechanical polishing on the sorption and solubility of heat-cured acrylic soaked in artificial saliva. The specimens that were mechanically polished and soaked in artificial saliva recorded lower mean solubility but higher mean sorption values than the sample group which received no surface treatment, soaked in artificial saliva. Neither the sorption nor the solubility values recorded were deemed to be statistically significant. The null hypothesis relating to objective four was therefore partially accepted.

Objective five was established to determine the effect of a light-cured varnish on the sorption and solubility of heat-cured acrylic soaked in distilled water. The specimens that were treated with the light-cured varnish and soaked in distilled water recorded lower mean sorption, but higher mean solubility values than the sample group which received no surface treatment, soaked in distilled water. Only the reduction in sorption was deemed to be statistically significant. The null hypothesis relating to objective five was therefore partially accepted.

Objective six was established to determine the effect of a light-cured varnish on the sorption and solubility of heat-cured acrylic soaked in artificial saliva. The specimens that were treated with the light-cured varnish and soaked in artificial saliva recorded lower mean sorption, but higher mean solubility values than the sample group which received no surface treatment, soaked in artificial saliva. Only the increase in solubility was deemed to be statistically significant. The null hypothesis relating to objective six was therefore partially accepted.

Objective seven was established to determine which surface treatment results in the least sorption and solubility of the heat-cured acrylic. The specimens that were treated with the light-cured varnish recorded lower mean sorption, but higher mean solubility values than the specimens that were mechanically polished. Both the lower sorption and higher solubility values recorded by the specimens that were treated with the light-cured varnish were statistically significant. The null hypothesis relating to objective seven was therefore partially accepted.

Finally, objective eight was established to determine which medium results in the least sorption and solubility of heat-cured acrylic. The specimens soaked in artificial saliva recorded lower sorption and solubility values than the specimens soaked in distilled water, but only the reduction in solubility was deemed to be statistically significant. The null hypothesis relating to objective eight was therefore accepted.

6.3.3 Overall conclusions

i. The application of surface treatments to Vertex™ *Rapid Simplified* heat-cured acrylic had a significant effect on the material's sorption and solubility properties.
ii. Mechanical polishing of prostheses fabricated from Vertex™ *Rapid Simplified* heat-cured acrylic will reduce their sorption and solubility, but the reduction cannot be expected to be statistically significant.
iii. The application of *Optiglaze*™ light-cured varnish to prostheses fabricated from Vertex™ *Rapid Simplified* heat-cured acrylic will significantly reduce the sorption of the material but will also result in significantly higher solubility values.
iv. When mechanical polishing is compared to *Optiglaze*™ light-cured varnish as a surface treatment, the sorption and solubility results indicate that mechanical polishing may be a more well-rounded surface treatment option.
v. *Optiglaze*™ light-cured varnish may be considered as an alternative surface treatment to mechanical polishing or used in conjunction with it as the sorption and solubility levels recorded were within the thresholds stipulated by ISO.
vi. The results indicate that the molecular composition of the medium in which the material is soaked affects the levels of sorption and solubility recorded. This suggests that the sorption and solubility properties of the material during function in the oral cavity may differ from those recorded during standardised tests.
vii. The results from this study and other comparable research indicate that denture wearers may benefit from having their prostheses cleaned and polished by a trained professional at calculated intervals.

6.4 Limitations

A careful reflective assessment of the research has enabled the researcher to identify the following limitations:

i. The effect that surface treatments and the composition of the medium had on the sorption and solubility of heat-cured acrylic were only determined for a single type-one, class-one denture base material.

ii. Studies have indicated that light-cured varnishes with different compositions may exhibit different sorption and solubility properties. In this study, only the effect of one light-cured varnish was investigated with respect to the sorption and solubility of heat-cured acrylic material.

iii. The formulae provided by ISO to calculate sorption and solubility make use of both the weight and volume of the specimens. When pumicing specimens and applying surface treatments, it is not possible for all the specimens to be of the exact same diameter and thickness. Even though all the specimens used were within the dimensions stipulated by ISO, one cannot ignore the fact that variation in specimen dimensions may have affected the sorption and solubility values calculated.

iv. The dimensions of the specimen as recommended by ISO significantly differ to that of a removable prosthesis fabricated from heat-cured acrylic. Literature indicates that the thickness of the material may affect its sorption properties. When comparing the dimensions and surface area of the specimens to that of acrylic prostheses, the possibility exists that the results of this study may not accurately represent the sorption and solubility of dental prostheses fabricated from heat-cure acrylic.

v. Unreacted residual monomer is one of the main solutes leaching from denture base materials during function and may result in various cytotoxic effects. The sorption and solubility of the material in this study were indicated by weight gained and lost. As the exact substances leaching from the specimens are unknown it is not clear whether the variables in this study may reduce the cytotoxicity of heat-cured acrylic material.

vi. The sorption and solubility of the specimens in this study were determined after being soaked for seven days, as recommended by ISO. It is therefore unclear what the long-term effects of surface treatments and the composition of the medium on the sorption and solubility of heat-cured acrylic materials are.

vii. The use of an artificial saliva solution aimed to simulate the sorption and solubility of heat-cured acrylic in the oral cavity during function. Due to the nature of the oral cavity and its associated bodily processes, replicating the molecular composition and consistency of human saliva is not possible. The use of this methodology and material can therefore not be a replacement for studies conducted in clinical situations with dentures in the human oral cavity.

6.5 Contribution to research

The sorption and solubility of heat-cured PMMA has a negative effect on the properties of the material, such as its strength, dimensional stability, and biocompatibility. These factors all directly affect the longevity, performance, and comfort of the prosthesis. The results from this study provide scientific evidence that surface treatment procedures are successful in reducing the sorption and solubility of heat-cured acrylic, although the extent of these reductions may not preserve the properties of dental protheses affected by sorption and solubility or increase the longevity of the appliance. The molecular composition of the medium in which the specimens were submersed affected the rate and extent of sorption and solubility of the heat-cured acrylic. It is therefore evident that the sorption and solubility properties of heat-cured denture base material during function in the oral cavity may differ from those recorded during standardised tests. The results of this study, together with those of cognate research, indicate that the application of surface treatments is still of vital importance, as they not only affect the levels of sorption and solubility of the material, but also promote the oral hygiene, comfort, and aesthetics of the appliance.

This research has produced a set of uniform results by strictly adhering to all ISO requirements, qualifying it to be used as a benchmark for future research into the effect of surface treatments on denture base materials. The results produced have quantified both the individual and interactive effect of surface treatments on the sorption and solubility of heat-cured acrylic and shown that these values may be influenced by the composition of the medium in which the material is soaked. The results and conclusions drawn from this study will assist future researchers, academics, dentists, dental technologists, and patients better to understand the clinical importance of a “polished” denture, and the effects that the molecular composition of a storage medium may have on the sorption and solubility properties of a prosthesis.

6.6 Recommendations

The findings of this study have been thoroughly appraised, and on the basis of this the following recommendations are made:

i. The results of this study indicate that a mechanical polishing procedure may reduce the levels of sorption and solubility of heat-cured acrylic. Corresponding research has highlighted that this reduction may be associated with the heat generated during the mechanical polishing procedure and the difference in surface roughness as a result of the surface treatment. It is recommended that future studies investigate these factors in isolation to determine their sole effect on the sorption and solubility of heat-cured acrylic.

ii. Both the surface treatments tested in this study reduced the sorption or solubility of heat-cured acrylic. Further research to determine the effect of these surface treatments on the physical, mechanical, and chemical properties of denture base material – such as its hardness, flexural strength, dimensional stability, surface roughness and biocompatibility – will be of significant value.

iii. Studies have indicated that light-cured varnishes with different compositions may exhibit different sorption and solubility properties. Further research to determine the effect that different types of light-cured varnishes may have on the sorption and solubility of denture base materials may indicate which light-cured varnish products are optimum with regard to reducing the sorption and solubility of heat-cured acrylic.

iv. As both mechanical polishing, and the application of *Optiglaze*™ light-cured varnish have been deemed as viable surface treatment options for heat-cure denture base material, future researchers may investigate the durability of these treatments by assessing the degradation of their surface roughness over time.

v. Unreacted residual monomer is one of the main solutes leaching from denture base materials during function and may result in various cytotoxic effects. It is therefore recommended that future researchers investigate which soluble substances are inhibited from leaching from the material due to the application of surface treatments.

vi. ISO recommends that the sorption and solubility of heat-cured denture base material be calculated after a seven-day immersion period. The results from this study therefore only indicate the effect of surface treatments and the composition of the medium over the short term. It is thus recommended that future research be conducted so as to determine the long-term effects of surface treatments and the composition of the medium on the sorption and solubility of denture base materials.

vii. This study found that the solubility of heat-cured acrylic was significantly lower when soaked in artificial saliva over a seven-day period. It is therefore recommended for prostheses to be soaked in distilled water after fabrication and overnight. This will aid in the leaching of soluble substances from the material and reduce the cytotoxic effects in the oral cavity.

viii. Based on the results of this study, *Optiglaze*™ light-cured varnish can be recommended as an alternative surface treatment to mechanical polishing or used in conjunction with it as the sorption and solubility levels recorded were within the thresholds stipulated by ISO. As the intaglio surfaces of dentures cannot be mechanically polished, it is recommended that these surfaces are treated with *Optiglaze*™ light-cure varnish and the outer surfaces of dentures are mechanically polished for optimum results.

ix. Finally, considering the results of this research as well as from cognate literature, it is advised that patients should not alter their prosthesis themselves, but rather have it

done by a trained professional, when the altered area should be re-treated with a surface treatment material. It can be recommended that denture wearers should have their prostheses cleaned and polished by a trained professional at calculated intervals.

6.7 Concluding remarks

Having completed this study, together with a very comprehensive review of the literature, the researcher has realised how sparsely documented are scientific studies relating to the field of dental technology. Specifically, there are very few publications that focus on the effect of surface treatments on the properties of denture base materials. Surface treatments are of crucial importance in producing prostheses that are both functional and aesthetically pleasing. These are factors that may affect the patient's self-esteem, social relations, oral health and general well-being. The results from this study and a review of comparable literature support the suggestion that dentures should be polished by a trained professional at calculated intervals. The application of a light-cured varnish to denture base material may be considered as an alternative to mechanical polishing or used in conjunction to produce optimum results. Finally, the submersion of the specimens in an artificial saliva solution, aimed at imitating the clinical situation of a polished denture in the oral cavity, established that the molecular structure of the liquid affects the rate of sorption and solubility experienced by the denture base material. It is therefore hoped that the findings of this research will be practically applied in dental laboratories as well as clinically by dental professionals and patients who make use of dentures.

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APPENDICES

Appendix A: Permission letter

Cape Peninsula
University of Technology

HEALTH AND WELLNESS SCIENCES RESEARCH ETHICS COMMITTEE (HW-REC)
Registration Number NHREC: REC- 230408-014

P.O. Box 1906 • Bellville 7535 South Africa
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Tel: +27 21 959 6917
Email: sethn@cput.ac.za

4 November 2019
REC Approval Reference No:
CPUT/HW-REC 2019/H13

Dear Mr Rian George Barnard

Re: APPLICATION TO THE HW-REC FOR ETHICS CLEARANCE

Approval was granted by the Health and Wellness Sciences-REC to Mr Rian George Barnard for ethical clearance on 4 November 2019. This approval is for research activities related to student research in the Department of Dental Science at this Institution.

TITLE: **Sorption and solubility of denture base material pre-and post – mechanical polishing**

Supervisor: Prof P Clarke-Farr and Mr A Latief

Comment: Ethical approval for this research is conditional to the appropriate MOU being established with UWC regarding work performed in collaboration.

Approval will not extend beyond 5 November 2020. An extension should be applied for 6 weeks before this expiry date should data collection and use/analysis of data, information and/or samples for this study continue beyond this date.

The investigator(s) should understand the ethical conditions under which they are authorized to carry out this study and they should be compliant to these conditions. It is required that the investigator(s) complete an **annual progress report** that should be submitted to the HWS-REC in December of that particular year, for the HWS-REC to be kept informed of the progress and of any problems you may have encountered.

Kind Regards

Dr. Navindhra Naidoo
Chairperson – Research Ethics Committee
Faculty of Health and Wellness Sciences

Appendix B: Data collection sheet

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10	Sample 11	Sample 12	Sample 13	Sample 14	Sample 15
W1															
W2															
Diffrence															
M1															
D1															
D2															
D3															
Avg Diameter															
T1															
T2															
T3															
T4															
T5															
Avg Thickness															
Radius															
Volume mm3															
M2															
W1															
W2															
Difference															
M3															
M1 µg															
M2 µg															
M3 µg															
Wsl															
Wsp															

Appendix C: Raw Data

No Surface Treatment, Soaked in Distilled Water.

Sample	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15
W1	1,03568	1,0271	1,05418	1,05912	1,00923	1,04199	1,06183	1,03873	1,05401	1,07527	1,0545	1,05458	1,0067	1,03399	1,08976
W2	1,03561	1,027	1,05416	1,05908	1,0092	1,04189	1,06169	1,03867	1,05392	1,07513	1,05437	1,05449	1,00657	1,03389	1,0897
M1 (g)	**1,03561**	**1,027**	**1,05416**	**1,05908**	**1,0092**	**1,04189**	**1,06169**	**1,03867**	**1,05392**	**1,07513**	**1,05437**	**1,05449**	**1,00657**	**1,03389**	**1,0897**
Volume	**909,5576**	**888,1517**	**904,5407**	**925,6605**	**873,1282**	**904,9165**	**926,2410**	**899,0558**	**911,2595**	**929,7316**	**923,7223**	**909,5576**	**871,1435**	**905,2056**	**937,4788**
M2 (g)	**1,0552**	**1,04685**	**1,0756**	**1,07921**	**1,02825**	**1,06193**	**1,08163**	**1,05928**	**1,07455**	**1,0979**	**1,07418**	**1,07453**	**1,02542**	**1,05288**	**1,11013**
W1	1,03534	1,0269	1,05412	1,0588	1,00915	1,04176	1,06155	1,03894	1,05388	1,07518	1,05424	1,05443	1,00648	1,03373	1,08967
W2	1,03532	1,02678	1,05401	1,05868	1,00901	1,04174	1,06153	1,03884	1,05375	1,07509	1,05419	1,05438	1,00637	1,03363	1,08954
M3 (g)	**1,03532**	**1,02678**	**1,05401**	**1,05868**	**1,00901**	**1,04174**	**1,06153**	**1,03884**	**1,05375**	**1,07509**	**1,05419**	**1,05438**	**1,00637**	**1,03363**	**1,08954**
M1 (µg)	1035610	1027000	1054160	1059080	1009200	1041890	1061690	1038670	1053920	1075130	1054370	1054490	1006570	1033890	1089700
M2 (µg)	1055200	1046850	1075600	1079210	1028250	1061930	1081630	1059280	1074550	1097900	1074180	1074530	1025420	1052880	1110130
M3 (µg)	1035320	1026780	1054010	1058680	1009010	1041740	1061530	1038840	1053750	1075090	1054190	1054380	1006370	1033630	1089540
Wsl	**0,31884**	**0,24771**	**0,16583**	**0,43212**	**0,21761**	**0,16576**	**0,17274**	**-0,18909**	**0,18655**	**0,04302**	**0,19486**	**0,12094**	**0,22958**	**0,28723**	**0,17067**
Wsp	**21,85678**	**22,59749**	**23,86847**	**22,17876**	**22,03571**	**22,31145**	**21,70062**	**22,73496**	**22,82555**	**24,53396**	**21,64070**	**22,15363**	**21,86781**	**21,26589**	**21,96316**

No Surface Treatment, Soaked in Artificial Saliva.

Sample	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15
W1	1,02262	1,05102	1,06605	0,9956	1,04818	1,02645	1,04409	1,05673	1,02018	1,02435	1,033	1,03426	1,03716	1,01191	1,01231
W2	1,02258	1,05097	1,06596	0,9955	1,04808	1,02641	1,04398	1,05668	1,02007	1,02424	1,03294	1,03417	1,0371	1,01175	1,01219
M1 (g)	1,02258	1,05097	1,06596	0,9955	1,04808	1,02641	1,04398	1,05668	1,02007	1,02424	1,03294	1,03417	1,0371	1,01175	1,01219
Volume	878,5394	912,1823	923,5868	876,1604	911,5036	903,4514	907,6116	907,9512	896,0222	904,7915	902,1210	901,7061	901,8269	883,4813	884,7159
M2 (g)	1,04177	1,0713	1,08646	1,01475	1,06812	1,0458	1,06374	1,07679	1,03975	1,04387	1,05235	1,05367	1,05622	1,03033	1,03085
W1	1,02289	1,05126	1,06626	0,99587	1,04853	1,02674	1,04449	1,05704	1,02066	1,02464	1,03336	1,03463	1,03752	1,0122	1,01258
W2	1,02267	1,05105	1,0659	0,99562	1,04832	1,02648	1,04419	1,05673	1,02029	1,02433	1,03302	1,03428	1,03718	1,01185	1,01229
W3	1,0226	1,05086	1,06585	0,99545	1,04813	1,0263	1,04402	1,05656	1,02011	1,02415	1,03285	1,0341	1,03701	1,01168	1,01211
M3 (g)	1,0226	1,05086	1,06585	0,99545	1,04813	1,0263	1,04402	1,05656	1,02011	1,02415	1,03285	1,0341	1,03701	1,01168	1,01211
M1 (µg)	1022580	1050970	1065960	995500	1048080	1026410	1043980	1056680	1020070	1024240	1032940	1034170	1037100	1011750	1012190
M2 (µg)	1041770	1071300	1086460	1014750	1068120	1045800	1063740	1076790	1039750	1043870	1052350	1053670	1056220	1030330	1030850
M3 (µg)	1022600	1050860	1065850	995450	1048130	1026300	1044020	1056560	1020110	1024150	1032850	1034100	1037010	1011680	1012110
Wsl	-0,02277	0,12059	0,11910	0,05707	-0,05485	0,12176	-0,04407	0,13217	-0,04464	0,09947	0,09976	0,07763	0,09980	0,07923	0,09042
Wsp	21,82031	22,40780	22,31517	22,02793	21,93080	21,58389	21,72736	22,28093	21,91910	21,79508	21,61573	21,70330	21,30121	21,10967	21,18194

Mechanical Polished, Soaked in Distilled Water

Sample	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
W1	1,06314	1,03401	1,02511	1,02272	1,02298	1,08475	1,06981	1,06024	1,03424	1,04908	1,01854	1,01391	1,05448	1,04255	1,08009
W2	1,063	1,03395	1,02499	1,02262	1,02286	1,08461	1,06968	1,06012	1,03413	1,04893	1,01841	1,01377	1,05433	1,04236	1,07993
M1 (g)	**1,063**	**1,03395**	**1,02499**	**1,02262**	**1,02286**	**1,08461**	**1,06968**	**1,06012**	**1,03413**	**1,04893**	**1,01841**	**1,01377**	**1,05433**	**1,04236**	**1,07993**
Volume	**922,5588**	**893,8998**	**877,0920**	**880,5077**	**885,4179**	**937,4100**	**922,2610**	**909,3140**	**897,5491**	**907,0012**	**877,8695**	**876,8207**	**903,9447**	**903,2355**	**936,7484**
M2 (g)	**1,08271**	**1,05381**	**1,04426**	**1,04192**	**1,04232**	**1,10506**	**1,08981**	**1,07972**	**1,05327**	**1,06822**	**1,03771**	**1,0326**	**1,07419**	**1,06172**	**1,1**
W1	1,06285	1,03395	1,02496	1,02263	1,0229	1,08461	1,06968	1,06005	1,03398	1,04879	1,01845	1,01371	1,05433	1,04229	1,07985
W2	1,0628	1,03384	1,02486	1,02248	1,02275	1,08446	1,06956	1,05996	1,03393	1,04872	1,01835	1,01361	1,05424	1,04221	1,07976
M3 (g)	**1,0628**	**1,03384**	**1,02486**	**1,02248**	**1,02275**	**1,08446**	**1,06956**	**1,05996**	**1,03393**	**1,04872**	**1,01835**	**1,01361**	**1,05424**	**1,04221**	**1,07976**
M1 (µg)	1063000	1033950	1024990	1022620	1022860	1084610	1069680	1060120	1034130	1048930	1018410	1013770	1054330	1042360	1079930
M2 (µg)	1082710	1053810	1044260	1041920	1042320	1105060	1089810	1079720	1053270	1068220	1037710	1032600	1074190	1061720	1100000
M3 (µg)	1062800	1033840	1024860	1022480	1022750	1084460	1069560	1059960	1033930	1048720	1018350	1013610	1054240	1042210	1079760
Wsl	**0,21679**	**0,12306**	**0,14822**	**0,15900**	**0,12424**	**0,16002**	**0,13012**	**0,17596**	**0,22283**	**0,23153**	**0,06835**	**0,18248**	**0,09956**	**0,16607**	**0,18148**
Wsp	**21,58128**	**22,34031**	**22,11855**	**22,07817**	**22,10256**	**21,97544**	**21,95691**	**21,73067**	**21,54757**	**21,49942**	**22,05339**	**21,65779**	**22,06993**	**21,60012**	**21,60666**

Mechanical Polishing, Soaked in Artificial Saliva

Sample	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
W1	1,01866	1,04981	1,04454	1,03671	1,04319	1,03856	1,03121	1,0307	1,01388	1,00333	0,98827	1,01176	1,04908	1,03893	1,03094
W2	1,01855	1,04975	1,04448	1,03665	1,04311	1,03848	1,03114	1,03059	1,01379	1,00324	0,98822	1,0117	1,04897	1,03882	1,03084
M1 (g)	**1,01855**	**1,04975**	**1,04448**	**1,03665**	**1,04311**	**1,03848**	**1,03114**	**1,03059**	**1,01379**	**1,00324**	**0,98822**	**1,0117**	**1,04897**	**1,03882**	**1,03084**
Volume	**891,8518**	**902,2941**	**919,1877**	**880,3354**	**900,6007**	**891,4375**	**883,7245**	**893,4650**	**871,9919**	**876,6219**	**852,3474**	**874,6137**	**906,2618**	**889,3835**	**902,0286**
M2 (g)	**1,0382**	**1,06959**	**1,06445**	**1,05643**	**1,06293**	**1,05829**	**1,05063**	**1,04992**	**1,03294**	**1,02206**	**1,00671**	**1,0308**	**1,06842**	**1,05832**	**1,0499**
W1	1,01888	1,04993	1,04484	1,03696	1,04344	1,03885	1,03138	1,03092	1,01415	1,00362	0,98854	1,01214	1,04933	1,03924	1,03119
W2	1,01865	1,04972	1,04461	1,03674	1,04318	1,03861	1,03116	1,03066	1,01387	1,00337	0,98831	1,0119	1,04906	1,03899	1,03096
W3	1,01857	1,04963	1,04451	1,03661	1,04306	1,03849	1,03108	1,03055	1,01373	1,00328	0,98817	1,01174	1,04895	1,03885	1,03081
M3 (g)	**1,01857**	**1,04963**	**1,04451**	**1,03661**	**1,04306**	**1,03849**	**1,03108**	**1,03055**	**1,01373**	**1,00328**	**0,98817**	**1,01174**	**1,04895**	**1,03885**	**1,03081**
M1 (µg)	1018550	1049750	1044480	1036650	1043110	1038480	1031140	1030590	1013790	1003240	988220	1011700	1048970	1038820	1030840
M2 (µg)	1038200	1069590	1064450	1056430	1062930	1058290	1050630	1049920	1032940	1022060	1006710	1030800	1068420	1058320	1049900
M3 (µg)	1018570	1049630	1044510	1036610	1043060	1038490	1031080	1030550	1013730	1003280	988170	1011740	1048950	1038850	1030810
Wsl	**-0,02243**	**0,13299**	**-0,03264**	**0,04544**	**0,05552**	**-0,01122**	**0,06789**	**0,04477**	**0,06881**	**-0,04563**	**0,05866**	**-0,04573**	**0,02207**	**-0,03373**	**0,03326**
Wsp	**22,01038**	**22,12139**	**21,69307**	**22,51415**	**22,06305**	**22,21132**	**22,12228**	**21,67964**	**22,03002**	**21,42315**	**21,75169**	**21,79248**	**21,48386**	**21,89157**	**21,16341**

Light Cure Varnish, Soaked in Distilled Water

Sample	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15
W1	1,04906	1,0789	1,05349	1,05892	1,02406	1,0905	0,9816	1,01552	1,04685	1,04435	1,07225	1,06481	1,04441	1,05033	1,06146
W2	1,04894	1,07871	1,05336	1,05874	1,0239	1,09033	0,98148	1,01542	1,04673	1,0442	1,07209	1,06465	1,04424	1,05017	1,06127
M1 (g)	**1,04894**	**1,07871**	**1,05336**	**1,05874**	**1,0239**	**1,09033**	**0,98148**	**1,01542**	**1,04673**	**1,0442**	**1,07209**	**1,06465**	**1,04424**	**1,05017**	**1,06127**
Volume	**928,6526**	**957,1920**	**919,9428**	**915,3153**	**897,5121**	**963,2738**	**866,3267**	**900,7915**	**919,7536**	**918,1516**	**938,8258**	**927,5039**	**912,9603**	**916,6450**	**930,5676**
M2 (g)	**1,06891**	**1,09916**	**1,07314**	**1,07859**	**1,04293**	**1,11071**	**0,99969**	**1,03428**	**1,06616**	**1,06339**	**1,09203**	**1,08403**	**1,06352**	**1,06927**	**1,08032**
W1	1,0487	1,07865	1,05318	1,05858	1,02391	1,09018	0,9814	1,01526	1,04644	1,04411	1,07201	1,06459	1,04416	1,05002	1,061
W2	1,04869	1,07861	1,05316	1,05852	1,02388	1,09009	0,98135	1,01518	1,04636	1,04393	1,07183	1,06453	1,04404	1,04985	1,06088
M3 (g)	**1,04869**	**1,07861**	**1,05316**	**1,05852**	**1,02388**	**1,09009**	**0,98135**	**1,01518**	**1,04636**	**1,04393**	**1,07183**	**1,06453**	**1,04404**	**1,04985**	**1,06088**
M1 (µg)	1048940	1078710	1053360	1058740	1023900	1090330	981480	1015420	1046730	1044200	1072090	1064650	1044240	1050170	1061270
M2 (µg)	1068910	1099160	1073140	1078590	1042930	1110710	999690	1034280	1066160	1063390	1092030	1084030	1063520	1069270	1080320
M3 (µg)	1048690	1078610	1053160	1058520	1023880	1090090	981350	1015180	1046360	1043930	1071830	1064530	1044040	1049850	1060880
Wsl	**0,26921**	**0,10447**	**0,21740**	**0,24035**	**0,02228**	**0,24915**	**0,15006**	**0,26643**	**0,40228**	**0,29407**	**0,27694**	**0,12938**	**0,21907**	**0,34910**	**0,41910**
Wsp	**21,77348**	**21,46905**	**21,71874**	**21,92687**	**21,22534**	**21,40617**	**21,16984**	**21,20357**	**21,52751**	**21,19476**	**21,51624**	**21,02417**	**21,33718**	**21,18596**	**20,89048**

Light Cure Varnish, Soaked in Artificial Saliva

Sample	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15
W1	1,02776	1,07439	1,033	1,08652	1,06938	1,06245	1,04586	1,06588	1,08619	1,03556	1,08327	1,07638	1,13853	1,02089	1,07687
W2	1,02774	1,07437	1,03292	1,08649	1,06932	1,06243	1,04576	1,0658	1,08612	1,0354	1,0832	1,07633	1,13852	1,02087	1,07684
M1 (g)	**1,02774**	**1,07437**	**1,03292**	**1,08649**	**1,06932**	**1,06243**	**1,04576**	**1,0658**	**1,08612**	**1,0354**	**1,0832**	**1,07633**	**1,13852**	**1,02087**	**1,07684**
Volume	**893,8680**	**940,5234**	**902,9689**	**933,5300**	**934,0554**	**921,3079**	**909,8484**	**928,2788**	**934,2939**	**897,2163**	**939,4956**	**931,2151**	**993,2582**	**882,9574**	**930,1058**
M2 (g)	**1,04649**	**1,09523**	**1,0526**	**1,10677**	**1,08951**	**1,08254**	**1,06533**	**1,08603**	**1,10636**	**1,05505**	**1,1033**	**1,0959**	**1,1597**	**1,03935**	**1,09639**
W1	1,0276	1,07429	1,03275	1,08632	1,06919	1,06232	1,04575	1,06565	1,08611	1,03555	1,0831	1,07614	1,13829	1,02072	1,07671
W2	1,02755	1,07424	1,0327	1,08627	1,06913	1,06231	1,04561	1,06562	1,08593	1,03555	1,08296	1,07605	1,13824	1,02064	1,07668
M3 (g)	**1,02755**	**1,07424**	**1,0327**	**1,08627**	**1,06913**	**1,06231**	**1,04561**	**1,06562**	**1,08593**	**1,03555**	**1,08296**	**1,07605**	**1,13824**	**1,02064**	**1,07668**
M1 (µg)	1027740	1074370	1032920	1086490	1069320	1062430	1045760	1065800	1086120	1035400	1083200	1076330	1138520	1020870	1076840
M2 (µg)	1046490	1095230	1052600	1106770	1089510	1082540	1065330	1086030	1106360	1055050	1103300	1095900	1159700	1039350	1096390
M3 (µg)	1027550	1074240	1032700	1086270	1069130	1062310	1045610	1065620	1085930	1035550	1082960	1076050	1138240	1020640	1076680
Wsl	**0,21256**	**0,13822**	**0,24364**	**0,23566**	**0,20341**	**0,13025**	**0,16486**	**0,19391**	**0,20336**	**-0,16718**	**0,25546**	**0,30068**	**0,28190**	**0,26049**	**0,17202**
Wsp	**21,18881**	**22,31736**	**22,03841**	**21,95966**	**21,81884**	**21,95792**	**21,67394**	**21,98693**	**21,86678**	**21,73389**	**21,64992**	**21,31623**	**21,60566**	**21,19015**	**21,19114**

Appendix D: Mould

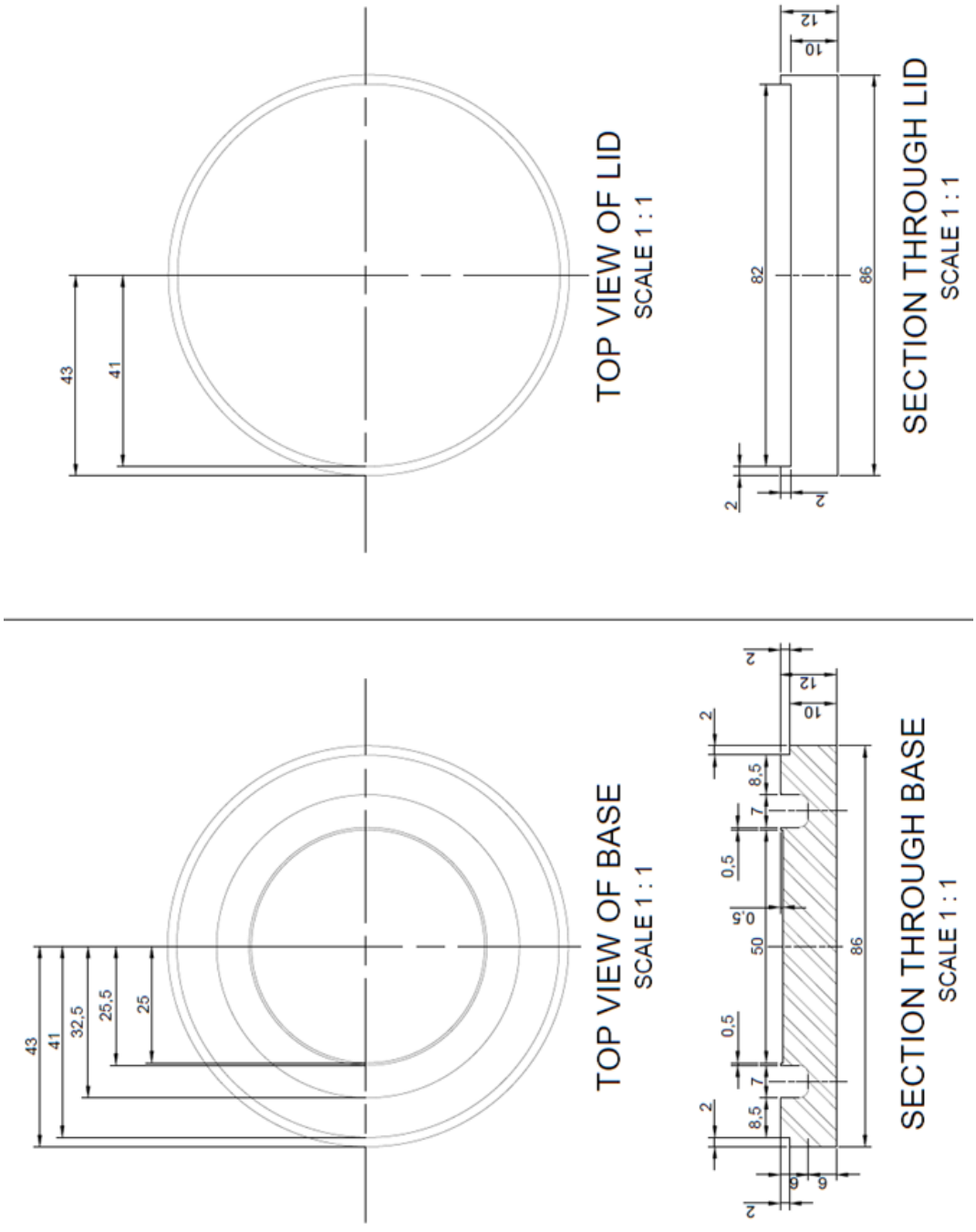

Figure 1: Design of stainless-steel mould

Appendix E: Images

Figure 2: Mould invested in flask

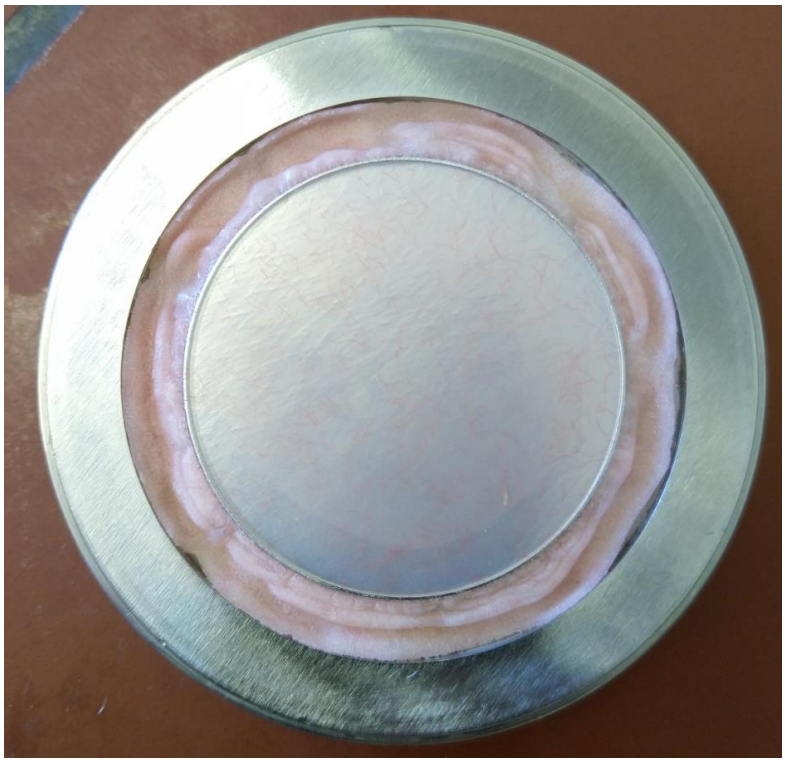

Figure 3: Processed acrylic specimen in mould

Figure 4: Specimens in custom-built drying rack

Figure 5: Specimens in desiccator

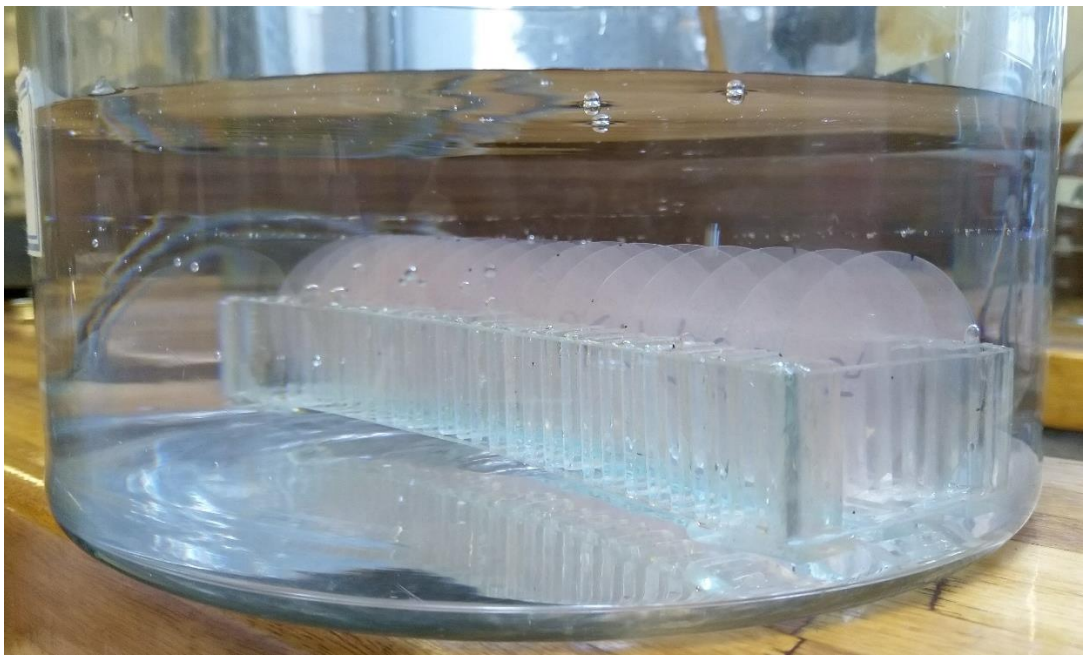

Figure 6: Submersed specimens in sealed glass bowl