Cape Peninsula University of Technology

MECHANICAL RETENTION OF ACRYLIC TEETH ONTO A PURE NYLON BASE

by

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DECLARATION

I, Nadine Olive van der Poel, declare that the contents of this thesis represent my own unaided work, and that the thesis 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**

ABSTRACT

A pure nylon denture base does not bond chemically to the acrylic teeth processed into the denture. A mechanical bond is created by boring retention holes (diatorics) into the tooth structure. Concerns are that this form of retention might be insufficient.

The purpose of this study is, firstly, to compare the retention of acrylic denture teeth in pure nylon dentures with that of teeth in conventional acrylic denture bases (the acrylic test pieces serving as the control standard), and secondly, to explore whether the technique prescribed for creating diatorics in acrylic teeth for use with pure nylon denture bases potentially has a weakening effect on the acrylic tooth structure.

Two sets of 26 identical anterior one-tooth test pieces were created. The first set, labelled N, comprises two different pure nylon denture base materials labelled N1 and N2 – all have diatorics in the acrylic teeth. The second set, labelled A, comprised the same acrylic denture base. The set labelled A1 is the control standard without diatorics in the acrylic teeth and the set labelled A2 has diatorics within the acrylic teeth. A compressive load was applied to these test pieces at an angle of 45 degrees on the palatal surface of the tooth until fracture occurred or maximum load was reached.

Resulting data from the first part of the research was analysed by One-Way ANOVA analysis. Resulting data for the second part of the research was analysed via the Chi-square cross- tabulation method.

The One-Way ANOVA test revealed that there is no statistical difference in the mean fracture or maximum load in Newton values between the two A (acrylic denture base) groups. There is also no statistical difference in the mean fracture or maximum load in Newton values between the two N (pure nylon denture base) groups. There is, however, a statistically significant difference in the mean fracture or maximum load in Newton values of Group A in comparison to Group N. The Chi-square cross-tabulation indicated that the A groups have very similar breakage patterns, and the N groups have similar breakage patterns respectively. It is concluded that the mechanical retention of acrylic denture teeth in pure nylon denture bases is weaker than the mechanical and chemical retention of acrylic denture teeth in acrylic denture bases. It is also concluded that when diatorics are created as prescribed within the tooth, these do not weaken the tooth structure.

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DEDICATION

For my family

Thank you for your support throughout my studies.
Without your love, encouragement and belief in me it would not have been possible.

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GLOSSARY

Terms and abbreviations	Definition/Explanation
Acrylic denture base	Denture base material manufactured from thermosetting polymethyl methacrylate (PMMA).
Adhesive failure	Denture tooth is dislodged with no trace of denture base material to it.
ANOVA	Statistical method for analysis of variance.
Cohesive failure	Remnants of the denture base material are found on the tooth and tooth remnants are found on the denture base material.
Diatorics	The retention holes bored into acrylic teeth.
Elastic deformation	Temporary shape change that is self-reversing after a low-stress force is removed.
Kg/sq mm	Kilogram per square millimetre (measurement of pressure)
Mm	Millimetre
Mesiodistal	The plane or diameter joining and relating to the mesial and distal surfaces of a tooth.
N	Newton
Notch sensitivity	The ability of a material to withstand the increased stress at an indentation or incision on an edge or at the surface of the material.
Nylon denture base	Denture base material manufactured from resilient synthetic polymers consisting of the recurring amide group CONH (specifically polyamide 12).
Plastic deformation	Permanent shape change during a high-stress force.

CHAPTER ONE
INTRODUCTION

1.1 Introduction

Although flexible denture base materials have been available since the 1950s (Stafford et al., 1986), it only reached the South African commercial market in 2010. This is due to two reasons: The restrictive legislative laws introduced in South Africa, known as apartheid, which caused economic and diplomatic sanctions to be passed against South Africa by the United Nations Security Council in 1962 (SAHO, 2000) and the very conservative prosthetic dental community in South Africa.

The company Zenith was the first dental supplier in South Africa to import a flexible denture base material, Deflex, in 2010. This material is manufactured in Buenos Aires, Argentina (Deflex, 2000). Shortly thereafter in 2011, Nova Dental Supply Company imported a product called Valplast from New York, United States of America (Valplast, 2004a). In 2012 Deon de Lange Dental Supply Company acquired Perflex from Netanya, Israel (Perflex, 2007a). Thereafter other dental supply companies started importing flexible denture base material to South Africa.

Flexible dentures break two major rules in dentistry. Firstly the nylon from which the flexible denture base materials are manufactured allows for relatively small dentures to be made due to the flexible retention achieved. These small dentures are very comfortable and popular with patients because the area in the mouth affected by the prosthetic appliance is reduced significantly, albeit that general dental practice dictates that a denture should not be made so small that it could be swallowed by the patient. Secondly, the flexibility of these dentures allow for dynamic prostheses in which each saddle of the denture reacts to forces within the mouth separately. Academic dental practice advocates rigid denture construction, relying on intricate fulcrum design to counteract and balance forces within the mouth to which the denture reacts as a whole. It is therefore understandable that dentistry communities throughout the world are opposed to flexible denture wear (even labelling flexible dentures as ‘gum strippers’ without the support of clinical study documentation). This attitude has led to little research being done on flexible dentures globally and a lack of description of flexible dentures in literature. In spite of this, the popularity of flexible dentures still grows in private dental practice.

The flexible denture base materials used in this study are Valplast and Perflex’s Flexi Nylon. They are both monomer free nylon denture base materials (see section 2.1). The acrylic denture base material used in this study is Vertex Rapid Simplified heat cure acrylic.

Valplast is generally known to be the very first nylon denture base material. It was developed by dental technicians, Arpad and Tibor Nagy, in their Master-Touch Dental Laboratory in New York, America in 1953. Initially, Valplast was an exclusive appliance category available from Master-Touch Dental Laboratory only. Valplast was introduced commercially to Italy, Greece, Germany, and the UK simultaneously under the respective brands Mastron and Valplast (Nagy, 2014).

In 1959 the Nagy brothers founded the Valplast Corporation and set up a network of regionally distributed Valplast franchised laboratories in the United States between 1959 and 1965. Included in this network were Master-Touch and 20 other laboratories that were offered specific territories to market Valplast. After 1965 the market opened widely throughout the United States and the product grew steadily for the next 30 years (Nagy, 2014).

By the year 2000, there were over 2500 Valplast processing laboratories. Formal technical courses were also introduced during this period to ensure uniformity in denture construction by laboratories. Valplast also became available in Mexico, Russia, China, and the rest of Europe. Valplast was the first flexible denture material to obtain an Encumbrance Certificate (CE Mark) when the European Union introduced this requirement for medical devices in the 1990's. Valplast was also the first exclusive flexible denture base material manufacturer to become International Organisation for Standardization (ISO 13485) certified (Nagy, 2014).

Perflex was founded in 2007 by dental technician Perla and partner Vidal Ben Simon (Perflex, 2007b). The Ben Simons started the company in Netanya, Israel after extensive research, engineering and improvements on aesthetic thermoplastic denture base materials (Perflex, 2007b).

Unlike the Valplast Corporation which specialises in the manufacture of one kind of denture base material, the Perflex Company provides an array of different kind of denture base materials. These include Flexi Nylon for flexible partial dentures, Acetal for tooth shade coloured clasps, Acry Free which is a non-allergenic acrylic material and T-Chrystal which is their new flagship thermoplastic material for all denture types (Perflex, 2007b). As in the case of the Valplast Corporation, Perflex provides extensive training to laboratories that use their system and complies with ISO 13485, ISO 9001 and CE certification (Perflex, 2007b).

Although the tests in this research show no statistical difference between the results for Perflex Flexi Nylon and Valplast, the physical differences between the materials are clear. The colour of the standard pink Valplast material is darker and more translucent than that of the standard pink Perflex Flexi Nylon. Perflex Flexi Nylon is slightly more rigid and harder to polish than Valplast. When grinding both materials, Valplast gives off a finer particle-sized waist material than Perflex Flexi Nylon.

As pure nylon denture base materials, Valplast and Perflex Flexi Nylon have one probable dilemma in common. When acrylic teeth are processed onto a pure nylon denture base, they do not bond chemically to the pure nylon denture base but rely on mechanical retention to keep the teeth in place. This is in direct contrast to acrylic denture base materials where acrylic teeth gain mechanical retention as well as chemical retention when processed onto an acrylic denture base.

Manufacturers of nylon denture base materials provide guidelines to ensure optimisation of the mechanical retention between the acrylic teeth and the pure nylon denture base. These include guidelines for boring diatorics (see section 2.5) into the acrylic teeth as well as guidelines for ensuring an adequate amount of intercoronal space. Dental technicians are concerned that even though they adhere strictly to guidelines from suppliers, the retention gained from this will not be sufficient to stop the teeth from ‘popping out’ or might even weaken the tooth structure, causing it to shear.

Minimal research has been done on nylon denture bases; there is also a paucity of research on the diatoric design within the denture teeth that provides the mechanical retention vital for flexible denture longevity. Therefore no satisfactory answer to this perceived concern currently exists.

The research in this study proposes to address these concerns, giving dental technicians a greater understanding of and enabling them to construct even more durable flexible dentures for their patients.

1.2 Statement of the research problem

A pure nylon denture base does not bond chemically to the acrylic teeth processed into the denture. In order to address this problem, a mechanical bond is created by boring retention holes (diatorics) into the tooth structure. The concern is that this form of retention might be insufficient and have a weakening effect on the acrylic tooth.

1.3 Objectives of the research

Firstly, the purpose of this research is to compare the retention of acrylic denture teeth in pure nylon denture bases with those in conventional acrylic denture bases (the latter serving as the control standard).

Secondly the research will investigate the possible influence of the diatorics (holes created within acrylic teeth for use in pure nylon denture bases) on the acrylic tooth structure.

1.4 Hypotheses

It is hypothesised that the bond strength of acrylic teeth onto a pure nylon denture base will be less than that of acrylic teeth onto a conventional acrylic denture base.

It is further hypothesised that diatorics should not influence the acrylic tooth structure detrimentally if created as prescribed.

CHAPTER TWO
LITERATURE REVIEW

2.1 Background on flexible nylon denture base materials

Nylon belongs to the thermoplastic polymer class known as polyamides (Sepúlveda-Navarro et al., 2011). It has a high tensile strength, high abrasion resistance, high resiliency, high flexural strength and excellent biocompatibility (Stern, 2007). Nylon was originally identified as a possible denture base material because it could be used in areas unsuited to acrylic denture bases (Sepúlveda-Navarro et al., 2011). These include dentures in need of higher levels of aesthetics, strength, accuracy, biocompatibility, comfort and flexibility for insertion (Prashanti et al., 2010).

The development of nylon as an alternative to polymethyl methacrylate (PMMA) denture base material started as early as the 1950s. Nylon 66 and 610 were used (Stafford et al., 1986), which presented specific disadvantages such as processing shrinkage resulting in warpage, deterioration in base colour because of high water absorption, surface roughness, inability to repair and reline, difficulty in polishing and a lack of chemical bond between the acrylic teeth and the nylon denture base (Stafford et al., 1986; Abuzar et al., 2010; Rickman et al., 2012).

Further satisfactory development of nylon denture base material was completed with the use of Nylon 12 in 1971 (Stafford et al., 1986). This material was a marked improvement on the previous generation of nylons, solving the problems with water absorption and stiffening the material by adding short glass fibres (Stafford et al., 1986; Abuzar et al., 2010). The linear molecular formula for Nylon 12 is $C_{12}H_{23}NO$ multiple (Chemnet 1997, Chemindustry, 1999). A graphic representation of nylon 12 can be found in Figure 2.1.

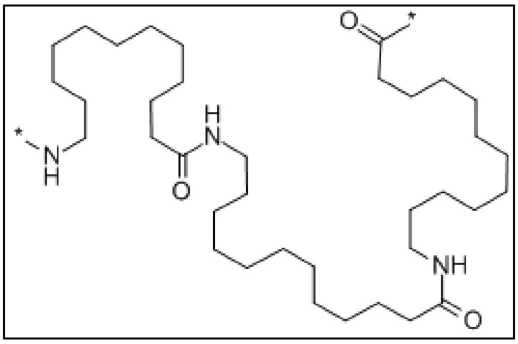

Figure 2.1: Graphic representation of nylon 12 (Chemnet, 1997; Chemical Book, 2008)

Modern nylon denture base materials can be divided into two main groups: those containing monomers (Duraflex, Flexite, Proflex, Impact, etc.) and those that are monomer-free

(Valplast, Lucitone FRS, etc.) (Shamnur et al., 2010). The true nylon denture base materials (monomer-free) do not bond chemically with acrylic resin teeth. Creating mechanical retention within the tooth structure itself is the only means of retaining the teeth within the dentures (Dhiman & Chowdhury, 2009).

2.2 The attractive properties of pure nylon denture base materials

2.2.1 Improved aesthetics

Conventional partial removable dentures use unsightly metal clasps to facilitate denture retention (Hamanaka et al., 2011). Nylon denture base material provides an improved level of aesthetics for denture wearers. The semi-translucent tissue colour material picks up and blends into the gingival colour, making clasps almost invisible (Stern, 2007; Prashanti et al., 2010; Rickman et al., 2012). Figure 2.2 shows a flexible denture with a nylon clasp on a 22 tooth, which would normally be aesthetically displeasing when using metal clasps.

Figure 2.2: Improved aesthetics provided by a nylon denture (Barron Dental, 2012)

2.2.2 Use in areas with deep undercuts

The flexibility of nylon dentures allows for better retention and stability of the denture with less tooth modification (Abuzar et al., 2010; Pusz et al., 2010). It can be easily placed and removed from the mouth, even if used in areas where abutments have deep undercuts, thereby adding to the comfort of the wearer (Prashanti et al., 2010; Hamanaka et al., 2011). Figure 2.3 demonstrates the flexibility of a nylon denture.

Figure 2.3: Flexibility of nylon dentures
(Westview Dental practice, 2012)

2.2.3 Resistance to breakage

Nylon's crystalline polymer structure renders it insoluble in solvents. This property also adds to the material being heat resistant as well as giving it high strength with ductility (Sepúlveda-Navarro et al., 2011). In addition it has a predictable long-term performance with high fatigue endurance and good wear characteristics (Pusz et al., 2010). The material's lack of notch sensitivity and crack propagation, coupled with a high resistance to breakage, makes it even more attractive to prospective wearers (Negrutiu et al., 2005; Pusz et al., 2010; Rickman et al., 2012).

2.2.4 Comfort to patients

Nylon dentures are readily accepted by wearers because they are lighter in weight and of smaller design than acrylic dentures (Pusz et al., 2010; Rickman et al., 2012). The strength of nylon denture base materials allow technicians to make the dentures very thin, which further contributes to the comfort of the denture wearer (Prashanti et al., 2010; Pusz et al., 2010). Figure 2.4 shows the difference between acrylic denture size on the left and nylon denture size on the right.

Figure 2.4: The difference in acrylic and nylon denture size
(Armagh Dental lab, 2014)

The acrylic denture fills most of the palatal area creating less tongue space, altered speech patterns and food tactile sensation. The nylon denture is divided into two smaller sections, leaving most of the palate open, which is much less disturbing to the tongue, speech and the patient in general.

Full upper flexible nylon dentures have also been used successfully with patients that have microstomia – a condition where limited opening of the mouth causes difficulty in inserting and removing prostheses from the mouth. The flexibility of the denture allows for deformation of the denture in order to slide through the abnormally small mouth opening comfortably (Egan et al., 2012).

2.2.5 Biocompatibility

Nylon denture bases have a very low level of porosity, making them impervious to oral fluids (Negrutiu et al., 2005; Pusz et al., 2010). This reduces the amount of stains, odours, and biological build up on the dentures. It also ensures the colour and dimensional stability of the dentures (Pusz et al., 2010). The material contains no monomers or metals, which are usually the main cause of allergic reactions, thereby making the material user-friendly (Abuzar et al., 2010; Prashanti et al., 2010: Pusz et al., 2010).

A study of mucus membrane irritation in hamsters was conducted by NAMSA (North American Science Associates) using nylon denture base test articles. These were sutured to the cheek mucosa of ten hamsters. After two weeks of exposure the hamsters were euthanatized and their oral mucosa recovered for microscopic tissue evaluation. The conclusion of the study was that the mucosa studied conformed to normal histomorphological limits and that the nylon denture base test articles were not considered an irritant to the hamster cheek mucosa (NAMSA, 1997).

2.2.6 Accuracy

The injection-moulded technique used to fabricate flexible dentures makes them more accurate than its packed acrylic counterparts (Prashanti et al., 2010).

2.3 Concerning properties of pure nylon denture base materials

2.3.1 Lack of chemical bond to acrylic teeth

As previously mentioned, true nylon denture base materials do not bond chemically with acrylic resin teeth. Creating mechanical retention within the tooth structure itself is the only means of retaining the teeth within the dentures (Dhiman & Chowdhury, 2009).

Manufacturers of nylon denture base materials provide guidelines to ensure optimisation of the mechanical retention between the acrylic teeth and the pure nylon denture base: Retention holes are bored into the acrylic tooth structure with special drills in a T-shape (see section 2.5) for optimum retention. The Deflex and Flex Star technique manuals recommend an amount of 1mm space of nylon denture base material between the denture tooth and tissues for sound denture construction (Deflex, 1999:2; Flex Star, 2012:5). Adequate interarch space with sufficient acrylic tooth length is needed for proper mechanical retention. Therefore inadequate vertical dimension is a contra-indication for flexible denture wear (Dhiman et al., 2009; Prashanti et al., 2010).

2.3.2 Surface roughness

Nylon denture base material needs to be polished in three stages. The first stage involves rough wet polishing with pumice. The second stage involves a form of burnishing with a Tripoli compound. The last stage involves buffing with a high shine compound (Valplast International Corporation, 2004:38; Perflex 2007:2; Flex Star, 2012:5). When polishing is done through this method an arithmetic surface roughness (Ra) of 0.146µm is achieved. Although this is rougher than the 0,046µm of polished PMMA, it is still below the accepted norm of 0.2µm Ra (Abuzar et al., 2010).

When one of these stages are ignored by the technician who is manufacturing the nylon denture, the surface roughness of the denture increases dramatically, causing an accumulation of plaque and the adherence of Candida albicans to the denture, which in turn causes denture-related stomatitis (Abuzar et al., 2010). Using incompatible chemicals to clean nylon dentures may also cause surface changes to the denture as described in section 2.6.4.

2.4 Difference in physical characteristics between acrylic and nylon

The difference in physical characteristics between an acrylic denture base material and a nylon denture base material is summarised in Table 2.1.

Table 2.1: Physical characteristics of acrylic denture base material vs. nylon denture base material (Stern, 2007)

Physical properties	Acrylic denture base	Pure nylon denture base
Specific gravity	1.16–1.20	1.04
Water absorption (24 hours)	0.4%	0.4%
Saturation by immersion	1.4%	1.2%
Young’s modulus (kg/sq mm)	280	150–180
Tensile strength (kg/sq mm)	5–7	8
Compressive strength (kg/sq mm)	8.6	10.3
Bonding strength (kg/sq mm)	8.5	8–10
Vickers hardness	20	14.5
Impact strength (kg/sq mm)	10.5	10–150
Process softens	135˚C	225˚C
Polymerises (in 6 hours)	71.12˚C	237.78˚C
Combustion	Burns	Non-inflammable

2.4.1 Specific gravity

Specific gravity refers to the ratio of the density of a solid or liquid to the density of water at 4 degrees Celsius. Water has a specific gravity equal to one. Materials with a specific gravity less than one will float on pure water, while materials with a specific gravity more than one will sink in water because they are denser than water (WhatIs, 1999). Acrylic denture base material has a higher specific gravity than nylon denture base material (Table 2.1). In my personal experience, Valplast floats on water while Perflex and Vertex acrylic sinks. A maxillary denture made from lighter nylon denture base material needs less retention to keep it from dislodging in the mouth than a heavier acrylic denture. Nylon dentures’ lightness makes it much less noticeable to the wearer.

2.4.2 Water absorption

Water absorption is calculated as the percent increase in weight of a material after exposure to water under specified conditions. These conditions are usually immersion in distilled water at room temperature for 24 hours (Prospector, 2014). Water absorption is important because it can influence the mechanical and conductive properties as well as the biocompatibility of a material (Pusz et al., 2010; Prospector, 2014). Although acrylic denture base material and nylon denture base material seems to have the same water absorption percentage over a 24 hour period, the immersion saturation percentage of acrylic denture base material is higher than nylon denture base material (Table 2.1). This implies that nylon denture base materials will have a higher biocompatibility and its mechanical properties will be more stable than that of acrylic denture base materials.

2.4.3 Young's modulus

Also known as elastic modulus, Young's modulus is a measure of stiffness and is expressed in force per unit area. It is calculated as the ratio of stress to strain. A material with a high elastic modulus is classified as rigid (Phillips, 1991:33-34; Anusavice, 2003:73,80-82). In Table 2.1 it is indicated that acrylic is more rigid than nylon which is more flexible. This property is the greatest difference between acrylic denture base material and nylon denture base material. It is the reason for nylon denture base materials being suitable for use in areas where acrylic denture base materials are not (see section 2.1).

2.4.4 Tensile strength

Tensile strength is also referred to as ultimate strength. It is defined as the maximum stress that a material can withstand while being pulled or stretched before failing or breaking. It is the highest point on a stress-stain curve and is measured in force per unit area. Materials that break sharply without plastic deformation during tensile testing are called brittle. Materials that undergo plastic deformation during tensile testing are classified as ductile (Phillips, 1991:38-39; Anusavice, 2003:77). Acrylic has a lower tensile strength than nylon (Table 2.1). Acrylic dentures will shatter under high stress, possibly cutting and causing trauma to soft tissues. High stress will cause nylon dentures to undergo elastic and then plastic deformation but never sudden breakage, making it the ideal denture base material for use by sportsmen and high risk workers such as firemen, policemen, etc.

2.4.5 Compressive strength

Compressive strength is the maximum stress that a material can withstand while under a crushing load before failing or breaking. Some materials fracture at its compressive strength limit while others undergo plastic deformation. Compressive strength is the highest point on a stress-stain curve and is measured in force per unit area (Phillips, 1991:38-39; Anusavice, 2003:77). Acrylic has a lower compressive strength than nylon (Table 2.1).

2.4.6 Bonding strength

Bonding new acrylic to an existing acrylic denture base is achieved easily; the same cannot be said for bonding new nylon to an existing nylon denture base. An etch has to be applied to the existing nylon denture base to soften it in order for the new nylon material to be injected onto it (Valplast International Corporation, 2004:42-43). Acrylic has a lower bonding strength than nylon (Table 2.1). This would indicate that although additions to nylon dentures are cumbersome, an addition done on a nylon denture would last longer than an addition done on an acrylic denture.

2.4.7 Vickers hardness

As a micro hardness test method, Vickers hardness Test tests the resistance of a material to indentation. A diamond indenter is used at a fixed force to make an indentation in the test materials. The indentation is measured and converted to a hardness value. The smaller the indentation, the harder the material (Newage, 2010). Acrylic has a higher Vickers hardness than nylon (Table 2.1). Although nylon denture base material does scratch and dent easier than acrylic denture base material, these dents and scratches do not cause notch sensitivity and crack propagation as with acrylic denture bases (Rickman et al., 2012).

2.4.8 Impact strength

Impact strength is the capability of a material to withstand sudden load application. During testing the impact energy needed to fracture a sample of material is measured. (Phillips, 1991:40-41; Anusavice, 2003:91-92). Acrylic has a lower impact strength than nylon (Table 2.1). As explained in section 2.4.4, with sudden load application acrylic dentures will shatter while nylon dentures will undergo elastic and plastic deformation but never sudden breakage, making it the ideal denture base material for use by sportsmen and high risk workers such as firemen, policemen, etc.

2.5 Former techniques for creating diatorics in acrylic denture teeth

Traditionally, diatorics are prepared in acrylic teeth using similar methods as described by Chai et al. (2000) and Bragaglia et al. (2009). A number eight rose head bur (Figure 2.5) is used at low speed on the ridge lap area of the tooth to create a cavity that is 2mm deep and 2.3mm in diameter.

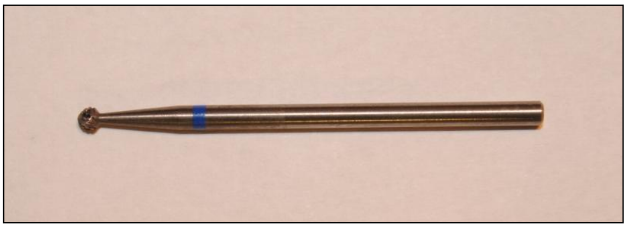

Figure 2.5: Rose head bur

The bond-strength testing by Bragaglia et al. (2009) indicated that the results of using these kinds of design diatorics as a means of increasing bond strength between acrylic denture base materials and acrylic denture teeth were highly ineffective (the test results rating it below the control group which received no enhancement treatments). It was noted by Bragaglia et al. (2009) that acrylic denture base material failure in the diatoric area could be due to the sharpness of the cavity borders that might cause a collaboration of stress concentration in this area.

In direct contrast, Takahashi et al. (2000) demonstrated that using diatorics could significantly improve the bond strength between acrylic denture bases and acrylic denture teeth. The acrylic denture base material that fills the diatoric space within the tooth structure creates a path of resistance to fracture in a different direction than the tooth- to denture-base resin interface, strengthening the bond mechanically.

The diatoric design used in the research of Dhiman and Chowdhury (2009) on complete upper nylon denture bases is described only as ‘mechanical undercuts in the centre of each tooth’. Their patients experienced dislodgement of teeth from the full upper nylon denture base progressively in 3 to 24 months, ranging from 3.4% to 34.5% respectively in 38 subjects. It was noted that modification in tooth diatoric design should be explored to overcome this problem.

2.6 New diatoric techniques appropriate for use in flexible denture design

A specialised bur called a twist drill is used to create all the diatoric holes (Figure 2.6). Twist drills are available in three sizes: 006, 009 and 012.

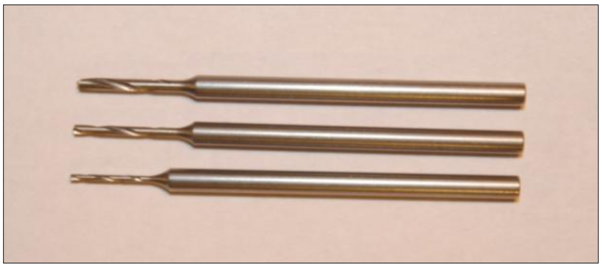

Figure 2.6: Twist drills in different sizes

Firstly, a centre hole is created from the ridge lap area of the tooth with a wider drill. Secondly a mesiodistal connection is drilled. The second drilling should connect with the centre hole – thus forming a T-shaped connection indicated in pink in Figure 2.7. When creating the diatorics care should be taken to avoid any visible openings on the facial and occlusal surfaces of the acrylic teeth. The instruction manuals cautions against creating more than one centre hole since it will not add to retentive strength, but will only serve to weaken the tooth structure (Deflex, 1999:2; Valplast International Corporation, 2004:28; Flex Star, 2012:5).

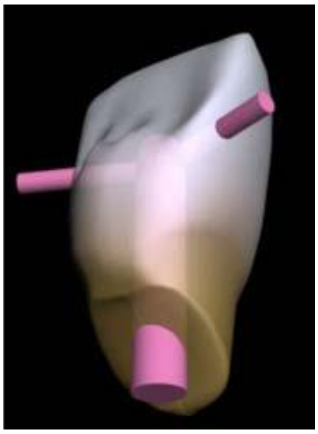

Figure 2.7: Diatorics created by twist drills
(Deflex, 1999:2)

2.7 Possible causes of mechanical retention failure between acrylic teeth and pure nylon denture bases

2.7.1 Lack of intercoronal space

Pure nylon flexible denture base materials retain acrylic teeth by mechanical retention only, therefore sufficient height of the denture tooth selected is needed (Prashanti et al., 2010).
Enough bulk of denture base material is also required mesio-distally, palatally and vertically to ensure enough mechanical bond strength (Singh et al., 2011). Patients with little vertical dimension are not suitable candidates for flexible nylon denture wear (Dhiman & Chowdhury, 2009).

2.7.2 Design of diatorics

The shape of the diatorics might cause failure in the denture base material passing through it and this possibility should be investigated further (Bragaglia et al., 2009; Dhiman et al., 2009).

It was noted by Bragaglia et al. (2009) that acrylic denture base material failure in the diatoric area could be due to the sharpness of the cavity borders resulting in stress concentration in this area.

2.7.3 Wax contamination

The bond between conventional acrylic denture base materials and acrylic denture teeth is severely affected by improper wax removal during processing as seen in the research of Cunningham and Benington (1996; 1999). The wax acts as a physical barrier between the tooth and denture base material, which prevents any kind of contact or chemical bonding between the materials (Thean et al., 1996; Geerts et al., 2012).
Similarly, the mechanical bond between the nylon denture base material and the acrylic teeth can be weakened by wax contamination. If the T-shape diatorics (construction explained in section 2.5) are drilled in the teeth during setup, some of the wax may remain in the junction

area of the T diatoric during processing, causing incomplete pressing of the nylon denture base material within the T. A weakened three-finger design will result. The T connection is vital for mechanical retentional strength (Singh et al., 2011).

2.7.4 Use of incompatible chemicals

It was noted by Yunus et al. (2005) that immersing a nylon denture base in an aldehyde-free, oxygen releasing disinfectant solution (Perform) increased the rigidity of the nylon denture base material.

A nylon denture base material instruction manual cautions against immersing the nylon denture base in bleach or cleansers containing bleach which may cause loss of colour pigment within the material (Valplast International Corporation, 2004:44). Using the manufacturer's own immersion solutions may reduce the risk of unwanted changes to the properties of the various nylon denture base materials (Rickman et al., 2012). These solutions comprise of potassium peroxymonopersulfate, citric acid, potassium bisulphate, magnesium carbonate, potassium sulphate, peppermint extract, potassium peroxydisulphate and sucrose (ValClean, 2014).

2.8 Testing technique

A review of national standards techniques that addressed denture tooth bonding was done by Cunningham and Benington (1996) as well as Patil et al. (2006). The reviews included the American National Standards, the Australian Standard, the International Organization for Standardization, the British and South African Standards, and German Specifications, as well as the Japanese Standard. These are summarised in Table 2.2, adapted from Patil et al. (2006).

From this review it is clear that all of these techniques only tested the bond strength of the artificial tooth to the denture base material in the ridge lap surface area of the tooth.
For the purpose of the research planned, one of these tests will have to be modified to accommodate the T shape diatorics needed for sufficient mechanical retention of denture teeth within the pure nylon denture base.

Table 2.2: The national standards for determining bond strength

National Standard	Year	Specimen Fabrication	Number of specimens	Type of load and cross-head speed of load testing machine	Acceptable bond strength values
The American National Standards / American Dental Association Specification no. 15 (ANSI/ADA 15)	Approved 1956 Revised 1985	Cylindrical shaft produced by incorporating acrylic teeth (>8.15mm diameter) in denture base resin; finally the shaft machined to a diameter of 6.35mm	3	Tensile 0.254mm/min	31MPa
The Australian Standard (AS 1626)	1974	Similar to ADA 15 but the length of the cylindrical shaft longer and clear acrylic denture resin used	3	Tensile 5mm/min	Not <32.0MPa
International Organization for Standardization for synthetic resin teeth (ISO 3336)	1977	A set of ground anterior teeth processed against resin held in a metal form simulating gumfitting dentures	Not stated	Shear-tensile (or peeling) rate of load application not stated	The bond satisfactory if fracture does not follow the tooth surface and some denture base resin remains attached to the tooth.
British Standard (BS 3990)	1980	Based on the ISO specification and the testing requirements are identical			
South African Standard (SABS 1342)	1982	Based on the ISO specification and the testing requirements are identical			
German Specification for denture base resin (DIN 13907) & for synthetic resin teeth (DIN 13914)	1983	Based on the ISO specification. However, a transverse three-point loading is carried out on 15×4×4mm rectangular specimens (tooth-resin interface positioned in the centre of the section)	6	Transverse 1mm/min	Not <70N/mm^2
Japanese Standard for Acrylic Resin Teeth (JIST 6506)	1989	Central incisors aligned at 45° taper to acrylic resin blocks of 8×10×20mm	10	Tensile 0.5mm/min (or a loading speed of 120N/min)	110N for upper teeth and 60N for lower teeth

The Japanese standard for acrylic resin teeth was used as the research method basis in the studies of Chai et al. (2000), Takahashi et al. (2000), and Bragaglia et al. (2009).

Bragaglia et al. (2009) state that an adaptation of the Japanese test is much more clinically plausible because it involves the true shape of the anterior teeth and simulates the direction of shear and compressive loads more accurately (Figure 2.8).

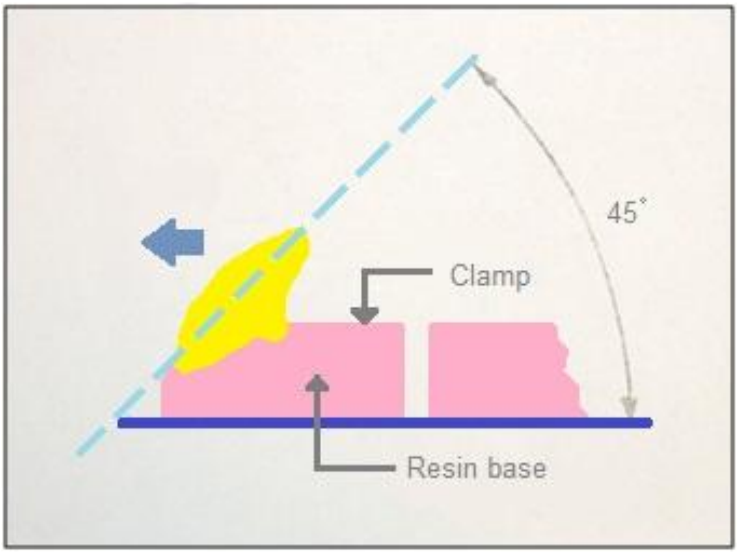

Figure 2.8: Japanese test
(Adapted from Cunningham and Benington, 1996)

Chai et al. (2000) Takahashi et al. (2000) and Bragaglia et al. (2009) applied a compressive load at a 45-degree angle (to the long axis of the tooth) on the palatal surface of anterior teeth until fracture occurred.

The compressive load is applied through a cylindrical pin at a crosshead speed of 0.5mm/min. The rate of loading is extremely important during testing because it could influence the results. The Japanese test is the only standard in which the stiffness factor of the testing machine was taken into account when the rate of loading was established (Cunningham & Bennigton, 1996). The fracture load is measured in Newton and can be converted into kilogram force (Bragaglia et al., 2009).

The Japanese standard for acrylic resin teeth sets the acceptable bond strength value at 110N for upper teeth and requires ten test pieces (Patil et al., 2006). Bond strength failure occurs either adhesively or cohesively. During adhesive failure the denture tooth is dislodged with no trace of denture base material to it. (Denture base material within the diatoric does not preclude failure from being adhesive.) During cohesive failure remnants of the denture base material are found on the tooth and tooth remnants are found on the denture base material (Takahashi et al., 2000).

According to Bragaglia et al. (2009), if during the bond strength testing the bond between the parts resist until the materials fail (the tooth shears without debonding or fracture occurs within the denture base material), the bond between the two would have fulfilled its requirements.

2.9 Other biological uses of nylon

Nylon in general has been used in other biological areas very successfully.

2.9.1. Surgical sutures

Surgical sutures are commonly known as stitches. They are used to hold together the skin or organs, repairing lacerations or closing incisions after surgery (Demetech, 2014; Dolphin sutures, 2014a). Polyamide sutures are made of nylon 6 and nylon 6.6 (Demetech, 2014). These sutures are non-absorbable and have a high tensile strength which leads to high resistance to breakage. It moves easily through tissue because of its uniform diameter and smooth texture, causing minimal tissue trauma. It also has less plasticity, making it easier to use than polypropylene suture and giving it more knot security. It is highly sterile, giving it minimal inflammatory reaction in tissue because it is free from irritants and impurities (Demetech, 2014; Dolphin sutures, 2014b).

2.9.2 Cell strainers

Cell strainers are made from strong nylon mesh with evenly spaced pores. They are used to isolate primary cells for single cell suspension from tissues. They remove clumps and debris from cell suspensions and clinical samples before analysis. Cell strainers are sterilized by gamma irradiation,easy to use and non-phyrogenic (Jetbiofil, 2012).

2.9.3 Dental implants

Inside the denture cap of the Locator implant system is a replaceable nylon retention insert. This insert is responsible for the amount of retention the denture receives from the implant and can be easily replaced when damaged or when another level of retentiveness is required (Dentsply, 2010). The nylon inserts come in different colours to indicate their level of retentativity. In Figure 2.9 the Locator system is depicted with the nylon retention insert in pink.

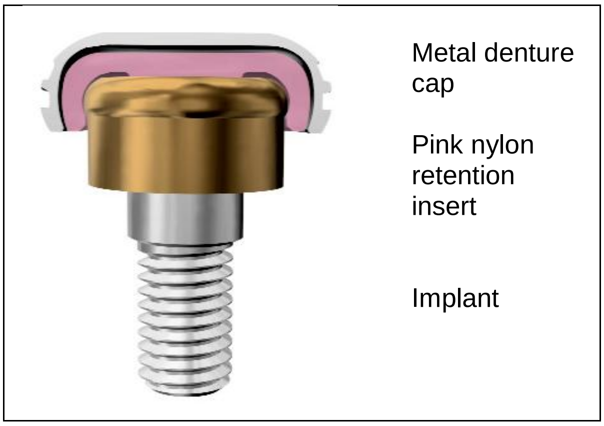

Figure 2.9: Locator system
(Adapted from Implant Direct, 2005)

2.9.4 Bone replacements

Traditionally the polymer of choice in orthopedic implant design has always been polyethylene (Qmed, 2014). Recent experimentation with three dimensional (3D) scanners and printing of bone and cartilage replacements has led to the evaluation of Nylon 618 as a 3D printing specific material. This material is well tolerated in the body, it is able to support the weight of a human, its pliability allows for some resilience and its smooth surface texture is ideal for joint movement (3ders, 2011).

CHAPTER THREE
EXPERIMENTAL DESIGN

3.1 Introduction

The existing national standards for determining the bond strength techniques only test the bond strength of the artificial tooth to the denture base material in the ridge lap surface area of the tooth. Therefore one of these tests was modified to accommodate the T-shape diatorics needed for sufficient mechanical retention of denture teeth within the pure nylon denture base.

In this study it was decided to use the Japanese Standard for Acrylic Resin Teeth as described by Cunningham & Benington, 1996, Chai et al., 2000, Takahashi et al., 2000, Patil et al., 2006 and Bragaglia et al., 2009 in their research as the starting point for the tests. The Japanese Standard is much more plausible clinically than the other standards, since it involves the true shape of the anterior teeth and simulates the direction of shear and compressive loads more accurately (Bragaglia et al., 2009).

3.2 Modifications made to Japanese Standard for Acrylic Resin Teeth

The Japanese Standard test applies a compressive load at a 45-degree angle (to the long axis of the tooth) on the palatal surface of an anterior tooth via cylindrical pin at a crosshead speed of 0.5mm/min until fracture occurs (Cunningham & Benington, 1996; Takahashi et al., 2000; Patil et al., 2006; Bragaglia et al. 2009). The Japanese Standard test calls for test sample blocks of 8×10×20mm with a 45-degree taper on the long side to which the ridge lap surface of the tooth is bonded (Figure 2.8) (Cunningham & Benington, 1996).

3.2.1 Modifications made to accommodate diatorics in acrylic teeth

In this study the test piece shape was modified so that the denture base area around the tooth included the neck as well as portions of the distal and mesial areas of the tooth in order to facilitate the T-shape diatoric design (Figure 3.1). It was critical that the extra denture base material added to these areas was precisely the same in all the test pieces to facilitate accuracy in the tests. Therefore one master mould was created and duplicated in silicone to create test pieces that were exactly alike.

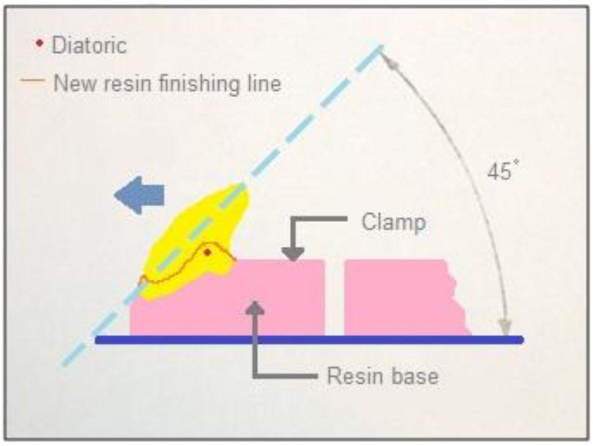

Figure 3.1: Modification 1 of the Japanese test
(Adapted from Cunningham & Benington, 1996)

3.2.2 Modifications made to accommodate the type of tensile testing machine

The tensile testing machine available to the researcher was a Tinius Olsen, Hounsfield Series S. This machine does not allow for horizontal testing, therefore the base of the test pieces had to be modified to fit in with the vertical testing machine. The test piece was rotated to fit into the machine (Figure 3.2). The base was also modified so that the test pieces could be accommodated in the specific grips of the machine. The dimensions of the test piece bases were therefore changed from 8×10×20mm to 8×10×48mm.

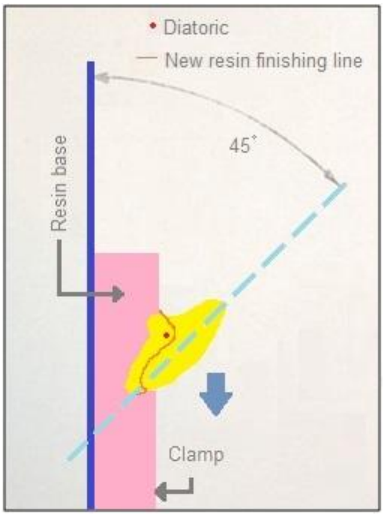

Figure 3.2: Modification 2 of the Japanese test

3.2.3 Modifications made to accommodate multiple materials and surfaces

Since the pure nylon denture base materials are flexible, a pilot test was done beforehand to ensure enough thickness of material for test piece stiffness so that the test piece itself did not bend during testing, which would have influenced the results of the tests.

The Japanese Standard for Acrylic Resin Teeth calls for a rejection of any individual test piece which has a fracture load failure varying more than 15% of the overall mean

(Cunningham & Benington, 1996). It should be remembered that this test was designed for testing the bond strength between an acrylic tooth and an acrylic denture base material on a single surface only. Taking into account that multiple materials would be used (acrylic as well as two different pure nylon denture bases) and that the retention area involved many sides of the acrylic tooth, variables greater than 15% were expected and therefore this rule was not applied to the tests to be done.

The Japanese Standard for Acrylic Resin Teeth applies a compressive load to the acrylic test pieces until fracture occurs. Given the plasticity of the pure nylon denture materials, the test pieces manufactured from these materials may not fracture, but the material around the teeth flexes and strains, until permanent deformation occurs. Therefore measurements were taken for fracture or maximum load applied.

3.3 Design and manufacture of the master test piece

A medium-sized patient's left central incisor Vita MFT acrylic tooth (see Appendix) was mounted onto an 8×10×48mm block of wax. The mesial and distal axis of the tooth was set at a 45-degree angle (Chai et al., 2000; Takahashi et al., 2000; Bragaglia et al., 2009) using a protractor (Figure 3.3).

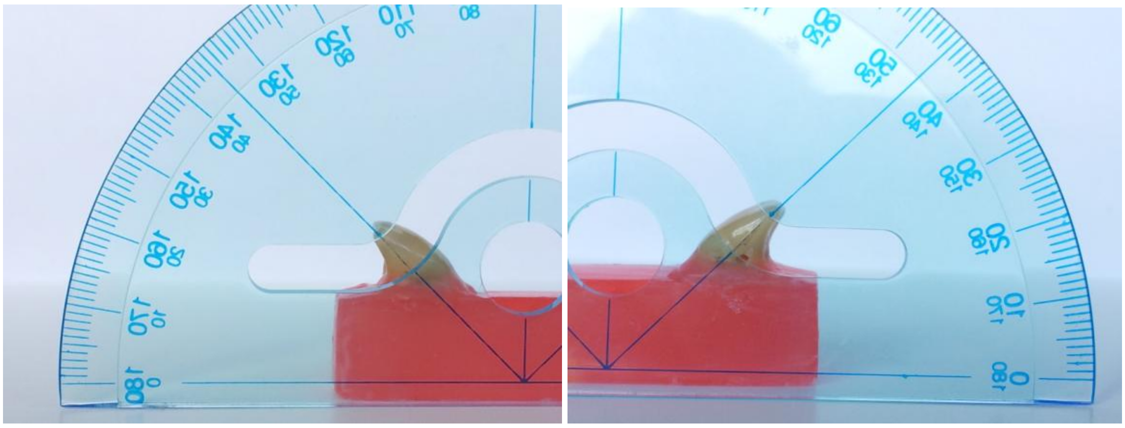

Figure 3.3: Mesial and distal axis of the tooth set to a 45-degree angle

The denture base area around the tooth was waxed up to include the neck as well as portions of the distal and mesial areas of the tooth to facilitate the T-shape diatoric design needed for mechanical retention. The master test piece was finished in Vertex Rapid Simplified acrylic (see Appendix) and polished to facilitate easier duplication.

3.4 Duplication of the master test piece into wax patterns

A custom duplication ring of 30×40×70mm was created to accommodate the master test piece for economical duplication. The master test piece was secured with wax to the bottom of the ring (Figure 3.4) and duplicated using highly accurate duplicating silicone (see Appendix).

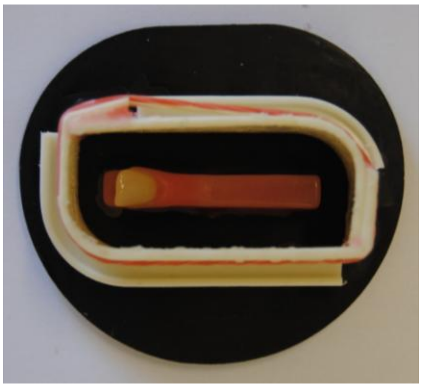

Figure 3.4: Custom duplication ring

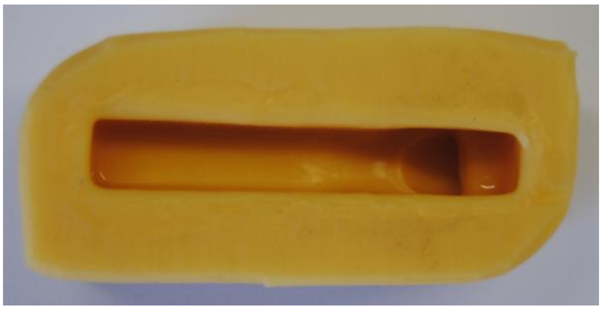

Figure 3.5: Single completed duplication

Figure 3.6: Some of the duplications as a group

Figures 3.5 and 3.6 show a single completed duplication as well as some of the duplications as a group. The same mould of a medium-sized patient's left central incisor acrylic tooth was carefully placed into each mould. The use of the same mould of tooth for all the test pieces eliminates variables during testing that may emanate from the use of different tooth sizes and shapes. A single kettle of Metrowax pink dental wax (see Appendix) was heated to exactly 70 degrees Celsius (Figures 3.7 and 3.8) and poured into the moulds to form 52 exact wax replicas of the master test piece (Figures 3.9 and 3.10). After cooling the wax overflow on the mould of each test piece was removed using a waxknife.

Figure 3.7: Kettle used to melt wax

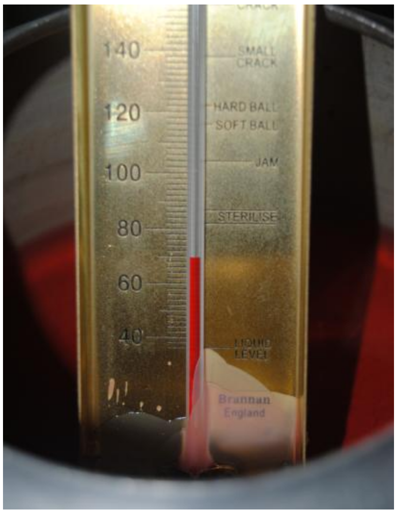

Figure 3.8: Temperature gauge at exactly 70 degrees Celsius

Figure 3.9: Wax poured into the moulds

Figure 3.10: 52 exact wax replicas of the master test piece

3.5 Explanation of the grouping of test pieces

The identical anterior one-tooth test pieces were divided into sets of 26. The first set was labelled N and comprised two different pure nylon denture base materials labelled N1 and N2 – all had diatorics in the acrylic teeth. The second set was labelled A and comprised the same acrylic denture base; the set labelled A1 was the control standard without diatorics in the acrylic teeth and the set labelled A2 had diatorics within the acrylic teeth. Figure 3.11 clarifies the explanation. All test pieces were marked in the wax stage to ensure any possible confusion in respect of grouping was eliminated.

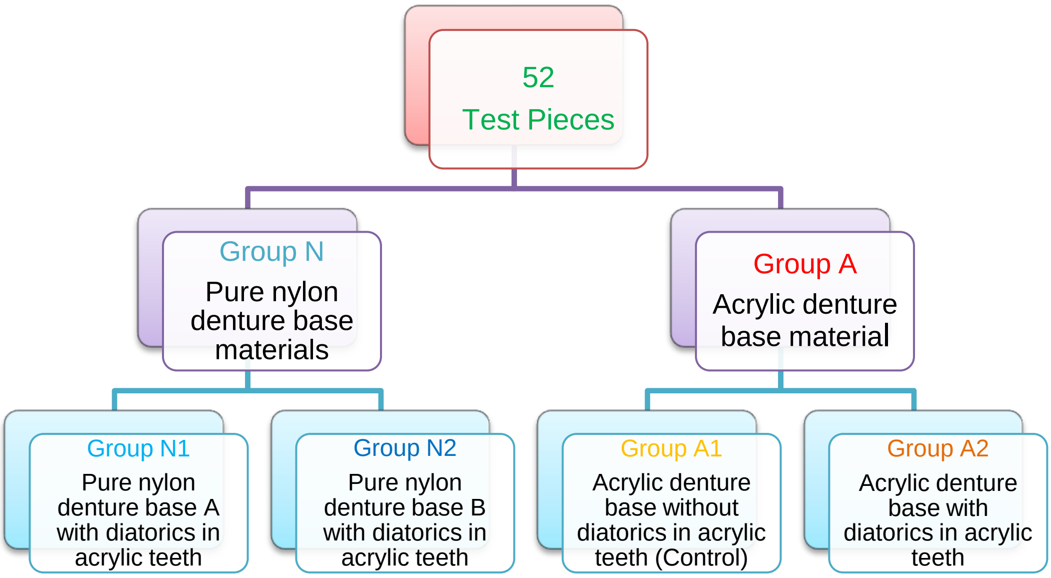

Figure 3.11: Grouping of test pieces

3.6 Flasking

The wax test pieces were embedded in the appropriate flasks for Group N and Group A (see Figures 3.12 and 3.13). Group A used plaster (see Appendix) as mould medium while Group N required yellow stone (see Appendix) as mould medium. The higher casting pressure technique used in flexible denture manufacture requires yellow stone be used as mould medium because white plaster is too soft. The wax patterns were eliminated using boiling water and cleaned thoroughly using a dewaxer.

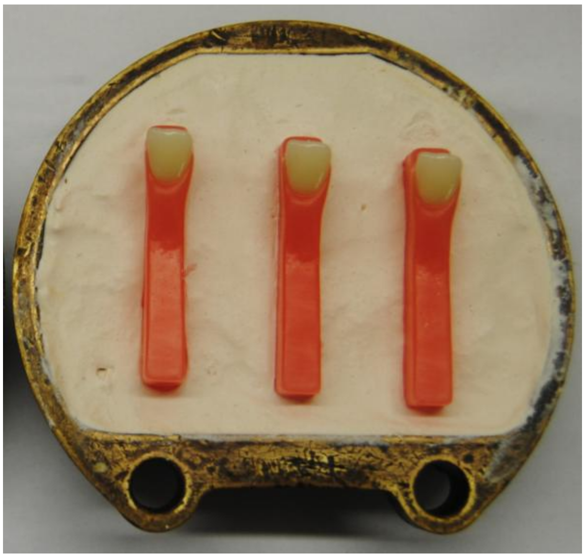

Figure 3.12: Embedding of wax test pieces in flask for acrylic denture bases

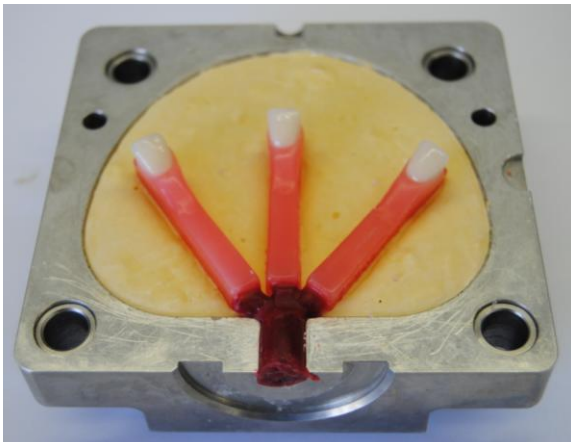

Figure 3.13: Embedding of wax test pieces in flask for pure nylon denture bases

3.7 Creating diatorics

Group N1, N2 and A2 needed T-shape diatorics. Group A1 served as the control standard; since T-shaped diatorics are not the norm when finishing acrylic dentures, no diatorics were needed in the control group.

3.7.1 Creating a jig for precise diatoric placement

One medium-sized patient's left central incisor acrylic tooth was used to create a jig to ensure that all the teeth had diatorics in exactly the same positions. Placing the diatorics in exactly the same position would eliminate variables during testing that could emanate from having diatorics in different positions on the acrylic teeth. Firstly, a centre hole from the ridge lap area of the tooth was created with a wider drill. Secondly, a mesio-distal connection was drilled into the tooth (Figure 3.14). The second drilling connected with the centre hole thereby forming a T-shaped connection (Deflex, 1999:2; Valplast International Corporation, 2004:28; Flex Star, 2012:5).

Figure 3.14: Diatoric T drilled into acrylic tooth

Orthodontic wire was placed into the T with extended arms and fastened to the tooth with superglue. Lab putty (see Appendix) was placed over the tooth in such a way that it enclosed the orthodontic wire in the mesial, distal and ridge lap areas where it emanated from the tooth (Figures 3.15 and 3.16).

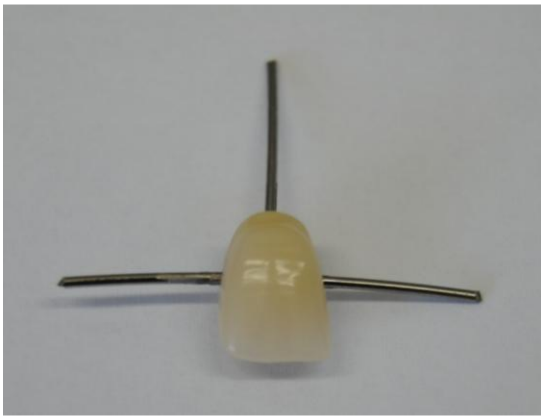

Figure 3.15: Orthodontic wire placed within the T diatoric

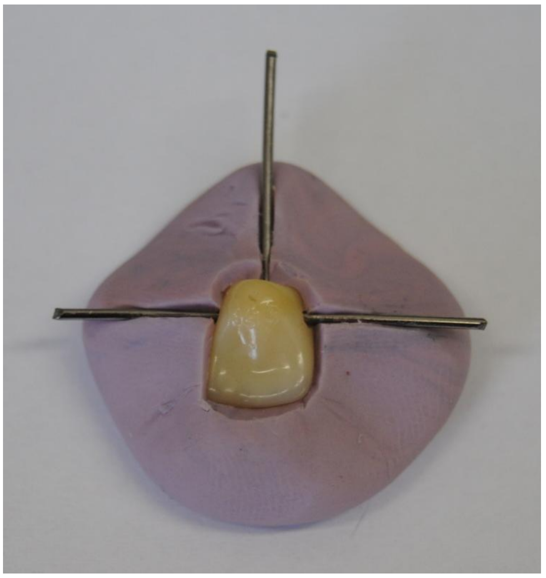

Figure 3.16: Lab putty placed over tooth and orthodontic wire

The tooth with the orthodontic wire was then removed from the lab putty mould and a new tooth put in its place. The lead of a mechanical pencil could then be driven into the shaft holes left by the orthodontic wires in the mould, leaving marks on the exact position that the drill should enter the tooth so that the diatorics made on all the teeth would be the same (see Figures 3.17, 3.18 and 3.19).

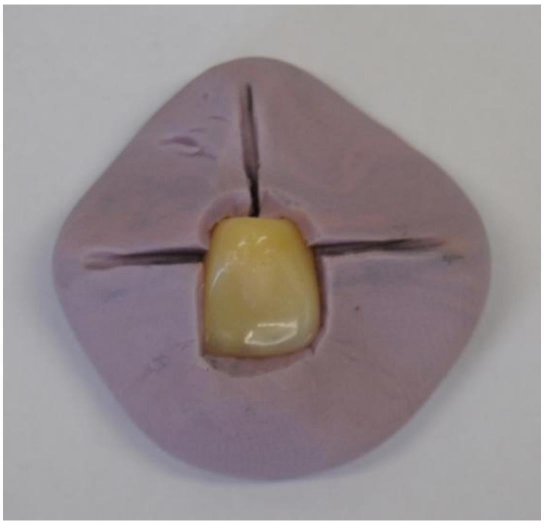

Figure 3.17: New tooth placed into mould

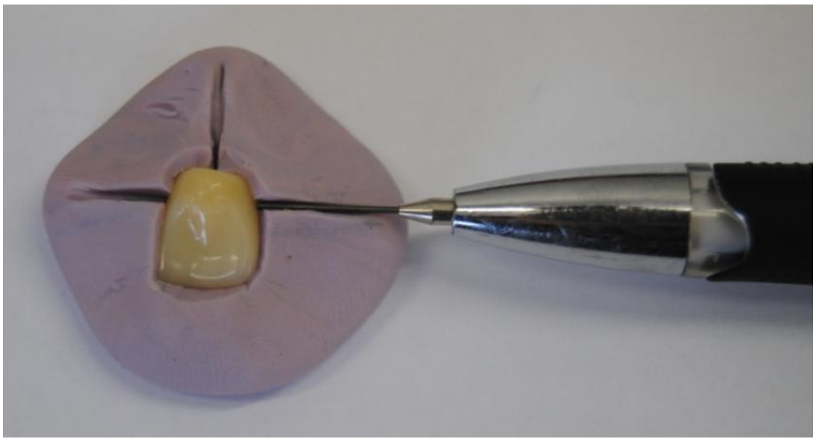

Figure 3.18: Lead of mechanical pencil placed in mould guide

Figure 3.19: Marks in lead indicating exact drilling position

3.7.2 Boring diatorics into the acrylic teeth

The acrylic teeth from groups N1, N2 and A2 were removed from their moulds and the diatorics bored into place as described above. They were fixed back into their moulds using a rubber-based glue (see Appendix) which would not take up any space within the mould or damage the surface of the acrylic teeth as sometimes happens when using superglue (Valplast International Corporation, 2004:28).

3.8 Finishing of the test pieces

Group N was pressed with the two kinds of pure nylon denture base materials (see Appendix) and Group A was packed using an acrylic denture base material (see Appendix), according to the manufacturers' instructions (see Appendix). Moulds were removed using a pneumatic chisel. Flash material and sprues were removed with a diamond disk and a fine carbide bur. No further finishing or polishing was done to the test pieces to ensure that they were worked as little as possible to eliminate latent cracks or stresses within.

3.9 Testing

The universal testing machine available to the researcher was a Tinius Olsen, Hounsfield Series S (Figure 3.20).

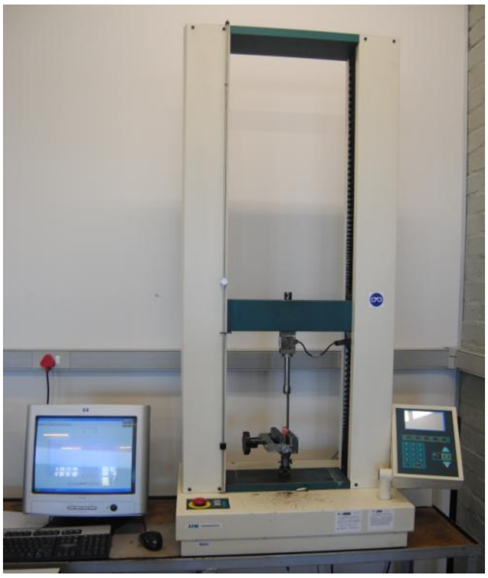

Figure 3.20: Tinius Olsen, Hounsfield Series S tensile testing machine

The test pieces were placed into the clamp and the grips tightened securely. The pin was dropped vertically until only touching the palatal surface of anterior teeth. If necessary, further adjustments to the positioning of the test piece were made (Figure 3.21).

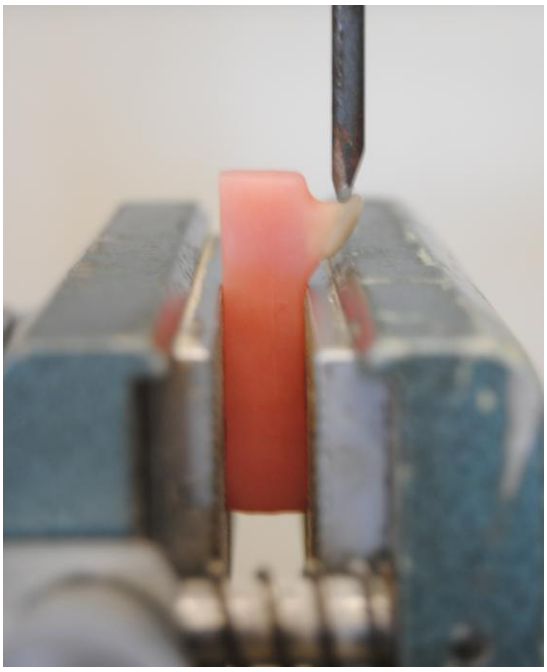

Figure 3.21: Test piece in grips of testing machine at starting position

A compressive load was applied by the pin at a crosshead speed of 0.5 mm/min until fracture or maximum load occurred (Cunningham & Benington, 1996; Chai et al., 2000; Takahashi et al., 2000; Patil et al., 2006; Bragaglia et al., 2009).

CHAPTER FOUR
TEST RESULTS

4.1 Introduction

During testing it became evident that although the Japanese Standard for Acrylic Resin Teeth is more plausible clinically than the other standards (because it encompasses the true shape of the anterior teeth and simulates the direction of shear and compressive loads more accurately (Bragaglia et al., 2009)), it differs from the clinical situation in four very important ways.

These are:

1. Lack of supporting teeth

In the natural situation, an anterior denture tooth is supported by the surrounding anterior teeth that bear and share the shear and compressive loads together – not as single units.

2. Angulation of the teeth

According to Wolfart et al. (2004), the ideal natural angulation of the central incisor axes is 2.5 degrees. Thus the Japanese Standard for Acrylic Resin Teeth (JIST 6506)'s angulation of 45 degrees is greatly exaggerated. In a pilot test the researcher noted that changing the angulation of the teeth to that of the suggested natural angulation increased the level of resistance of the test pieces dramatically.

3. Use of complete acrylic tooth structure

These tests have the advantage of using the complete acrylic central incisor tooth structure. In true cases intra-oral space is often a concern, which means that technicians have to trim the ridge lap and neck area of the acrylic tooth, which in turn leaves less tooth structure from which to create mechanical retention.

4. Load application

The test machine produced the same amount of load at a preset increase for a relatively short period of time on the test pieces. Clinically dynamic loads are applied to the denture teeth over the extended time of denture wear.

4.2 Test results

Test results were recorded as shown in Tables 4.1 to 4.4. Stress and strain graphs as recorded by the universal testing machine for each separate group are shown in Figures 4.1, 4.3, 4.5 and 4.7. The test machine attempts to make distinction between each individual test easier by assigning graph lines with different colours.

4.2.1 Group N1 (pure nylon denture base material A with diatorics in acrylic teeth)

Table 4.1: Group N1 – Pure nylon denture base material A with diatorics

Test piece	ID number	Fracture or maximum load in Newton	Extension in mm at fracture or maximum load	Description of specific area of fracture
1	1N11	126.9	1.270	Stretching and failure of nylon at mesiodistal diatoric exits on teeth
2	4N14	106.6	1.670	Stretching and failure of nylon at mesiodistal diatoric exits on teeth
3	2N13	99	2.050	Stretching and failure of nylon at mesiodistal diatoric exits on teeth
4	1N11	80.5	1.280	Stretching and failure of nylon at mesiodistal diatoric exits on teeth
5	2N14	73.8	1.500	Stretching and failure of nylon at mesiodistal diatoric exits on teeth
6	3N12	138.3	1.650	Stretching and failure of nylon at mesiodistal diatoric exits on teeth
7	1N11	99.5	1.87	Stretching and failure of nylon at mesiodistal diatoric exits on teeth
8	2N14	99.5	1.870	Stretching and failure of nylon at mesiodistal diatoric exits on teeth
9	3N13	131.6	1.620	Stretching and failure of nylon at mesiodistal diatoric exits on teeth
10	3N12	75	1.583	Stretching and failure of nylon at mesiodistal diatoric exits on teeth
11	3N12	82.7	0.940	Stretching and failure of nylon at mesiodistal diatoric exits on teeth
12	4N14	92.7	1.160	Stretching and failure of nylon at mesiodistal diatoric exits on teeth
13	2N13	83.5	1.410	Stretching and failure of nylon at mesiodistal diatoric exits on teeth

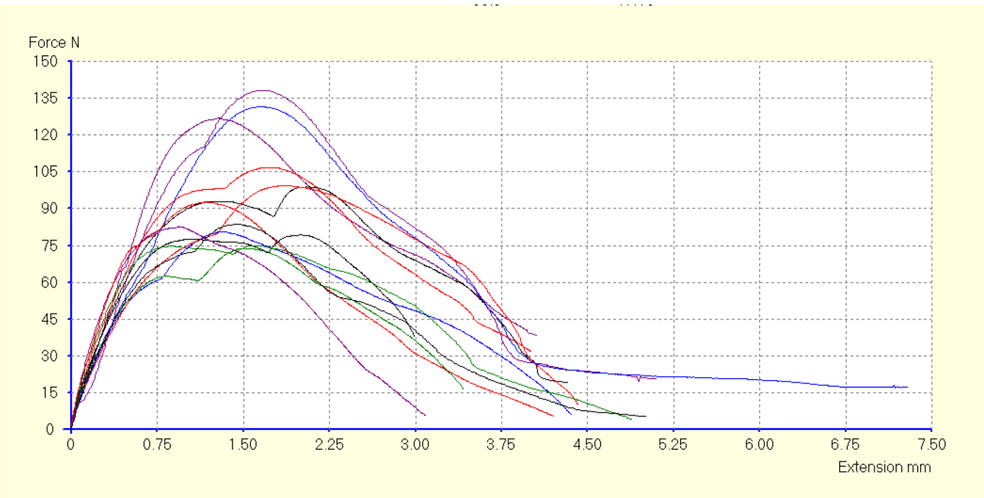

Figure 4.1: Stress and strain graph for Group N1 – Pure nylon denture base material A with diatorics

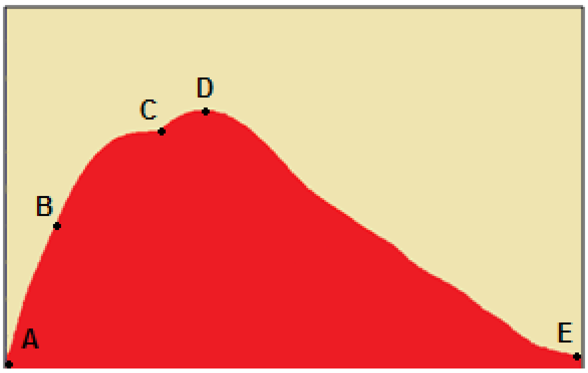

Figure 4.2: Typical Group N1 stress and strain graph

Figure 4.2 shows a typical Group N1 stress and strain graph. From starting point A to point B the test piece undergoes elastic deformation around the tooth area. From point B to C the test piece undergoes plastic deformation – during this period stretching and failure of the pure nylon denture base material occurs at the mesiodistal diatoric exits on the teeth. At point C the denture tooth bears down on the peripheral edge of the denture base material in the neck area of the tooth which increases its resistance and causes secondary plastic deformation up to point D. Point D is the point of maximum load for the test piece. Resistance lessens and further deformation occurs until test is ended at E.

4.2.2 Group N2 (pure nylon denture base material B with diatorics in acrylic teeth)

Table 4.2: Group N2 – Pure nylon denture base material B with diatorics

Test piece	ID number	Fracture or maximum load in Newton	Extension in mm at fracture or maximum load	Description of specific area of fracture
1	1N23	122.6	1.880	Snapping and failure of nylon at mesiodistal diatoric exits on teeth
2	3N22	65.3	1.0	Snapping and failure of nylon at mesiodistal diatoric exits on teeth
3	1N22	119.1	1.600	Snapping and failure of nylon at mesiodistal diatoric exits on teeth
4	1N22	116	0.936	Snapping and failure of nylon at mesiodistal diatoric exits on teeth
5	2N23	113	1.084	Snapping and failure of nylon at mesiodistal diatoric exits on teeth
6	3N24	100.6	1.096	Snapping and failure of nylon at mesiodistal diatoric exits on teeth
7	3N21	122.1	1.958	Snapping and failure of nylon at mesiodistal diatoric exits on teeth
8	2N23	82.3	0.940	Snapping and failure of nylon at mesiodistal diatoric exits on teeth
9	3N21	126.9	1.550	Snapping and failure of nylon at mesiodistal diatoric exits on teeth
10	4N24	81.2	2.240	Snapping and failure of nylon at mesiodistal diatoric exits on teeth
11	2N23	147.9	1.150	Snapping and failure of nylon at mesiodistal diatoric exits on teeth
12	2N24	166.8	1.275	Snapping and failure of nylon at mesiodistal diatoric exits on teeth
13	1N21	115.4	1.613	Snapping and failure of nylon at mesiodistal diatoric exits on teeth

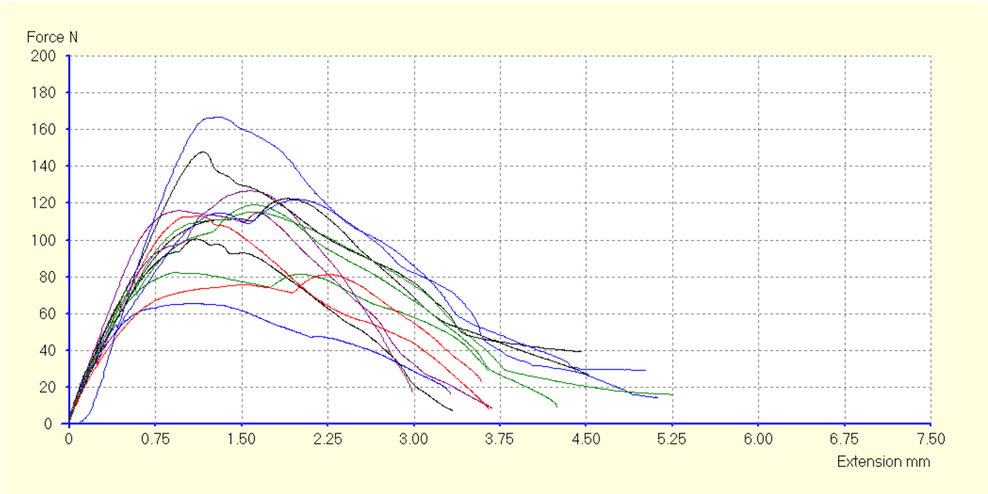

Figure 4.3: Stress and strain graph for Group N2 – Pure nylon denture base material B with diatorics

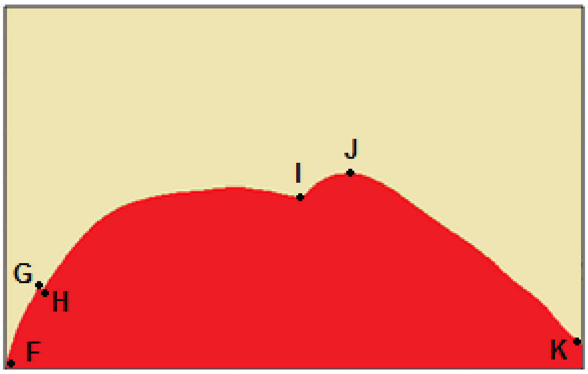

Figure 4.4: Typical Group N2 stress and strain graph

Figure 4.4 shows a typical Group N2 stress and strain graph. From starting point F to point G the test piece undergoes elastic deformation around the tooth area. At point G snapping and failure of the pure nylon denture base material occur at the mesiodistal diatoric exits on the teeth, plummeting resistance to point H. From point H to point I the test piece undergoes plastic deformation. At point I the denture tooth bears down on the peripheral edge of the denture base material in the neck area of the tooth which increases its resistance and causes secondary plastic deformation up to point J. Point J is the point of maximum load for the test piece. Resistance lessens and further deformation occurs until test is ended at K.

4.2.3 Group A1 (control – acrylic without diatorics in acrylic teeth)

Table 4.3: Group A1 – Acrylic denture base material without diatorics (control)

Test piece	ID number	Fracture or maximum load in Newton	Extension in mm at fracture or maximum load	Description of specific area of fracture (adhesive or cohesive)
1	4A13	Test machine crash	Test machine crash	Facial third of acrylic tooth – adhesive
2	2A12	550	2.82	Acrylic below tooth – adhesive
3	3A13	425	2.37	Two fractures: acrylic below tooth – adhesive/facial third of acrylic tooth – adhesive
4	2A11	640	2.38	Acrylic below tooth – adhesive
5	1A12	457	0.95	Facial third of acrylic tooth – slightly cohesive mesially
6	2A11	214	1.08	Acrylic below tooth – adhesive
7	3A14	554	1.7333	Facial third of acrylic tooth – slightly cohesive mesiodistally
8	1A11	302.5	2.963	Two fractures: acrylic below tooth – adhesive/facial third of acrylic tooth – slightly cohesive mesiodistally
9	1A12	806	2.720	Facial third of acrylic tooth – slightly cohesive mesiodistally
10	3A12	486	1.64	Facial third of acrylic tooth – slightly cohesive mesiodistally
11	2A11	340.4	1.190	Facial third of acrylic tooth – adhesive
12	3A13	527	1.92	Facial third of acrylic tooth – slightly cohesive mesiodistally
13	1A12	378	1.430	Facial third of acrylic tooth – slightly cohesive mesially

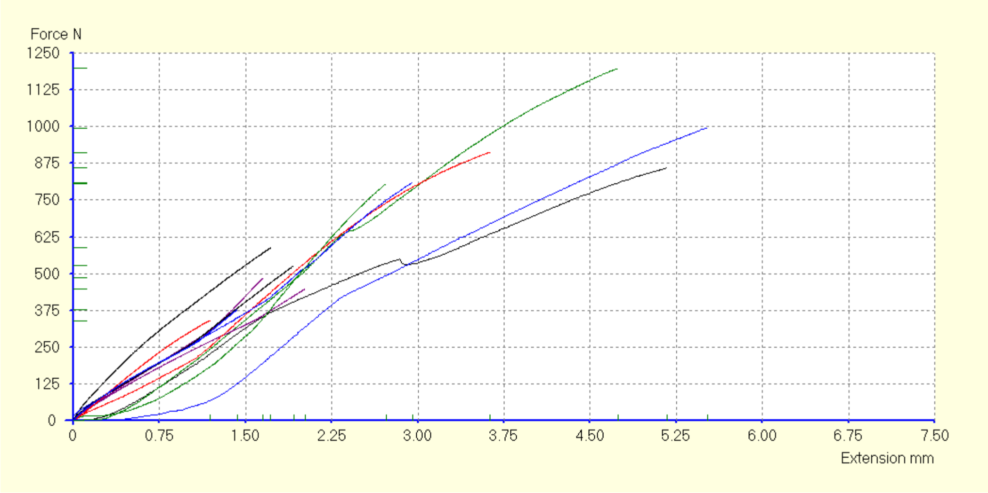

Figure 4.5: Stress and strain graph for Group A1 – Acrylic denture base material without diatorics

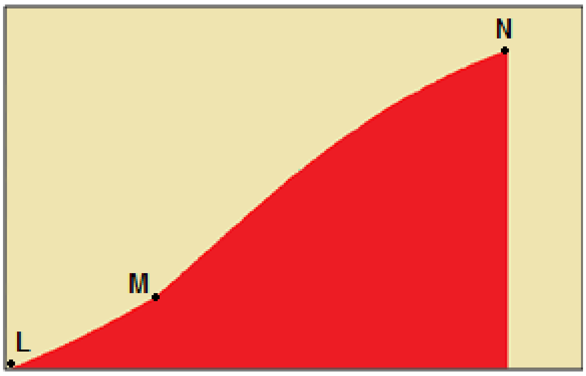

Figure 4.6: Typical Group A1 stress and strain graph

Figure 4.6 shows a typical Group N1 stress and strain graph. From starting point L to point M the test piece undergoes elastic deformation around the tooth area. At point M to point N plastic deformation occurs. At point N the test piece fractures and the test ends.

4.2.4 Group A2 (acrylic with diatorics in acrylic teeth)

Table 4.4: Group A2 – Acrylic denture base material with diatorics

Test piece	ID number	Fracture or maximum load in Newton	Extension in mm at fracture or maximum load	Description of specific area of fracture (adhesive or cohesive)
1	3A22	756	2.888	Acrylic below tooth – adhesive
2	3A22	1044	2.380	Two fractures: acrylic below tooth – adhesive/facial third of acrylic tooth – adhesive, very shallow
3	2A21	633	2.240	Two fractures: acrylic below tooth – adhesive/facial third of acrylic tooth – adhesive, very shallow
4	1A22	1031	2.728	One long fracture: along acrylic below tooth through facial third of acrylic tooth – cohesive mesiodistally, all along T of diatoric
5	2A21	1026	3.040	Facial third of acrylic tooth – slightly cohesive mesiodistally, along mesiodistal arm of diatoric T
6	1A23	1030	2.940	Acrylic below tooth – adhesive
7	4A22	931	3.072	Acrylic below tooth – adhesive
8	1A23	960	3.072	Two fractures: acrylic below tooth – adhesive/facial third of acrylic tooth – slightly cohesive mesiodistally, along mesiodistal arm of diatoric T
9	4A22	1030	3.628	Acrylic below tooth – adhesive
10	3A21	727	2.220	Two fractures: acrylic below tooth – adhesive/facial third of acrylic tooth – slightly cohesive mesiodistally, all along T of diatoric
11	1A23	790	2.090	Facial third of acrylic tooth – slightly cohesive mesiodistally, along mesiodistal arm of diatoric T
12	2A21	1041	2.450	Two fractures: acrylic below tooth – adhesive/facial third of acrylic tooth – slightly cohesive mesiodistally, at T junction area of diatoric
13	3A21	1163	3.032	Two fractures: acrylic below tooth – adhesive/facial third of acrylic tooth – adhesive, very shallow

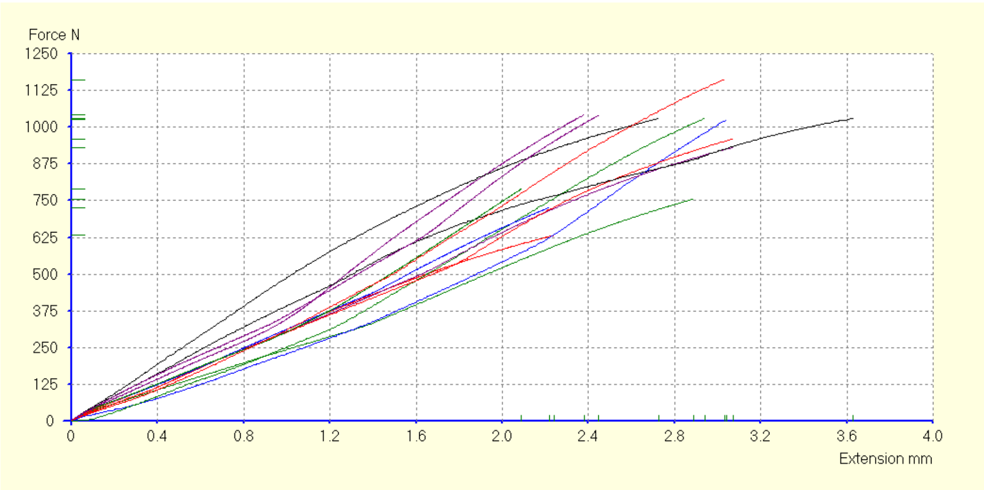

Figure 4.7: Stress and strain graph for Group A2 – Acrylic denture base material with diatorics

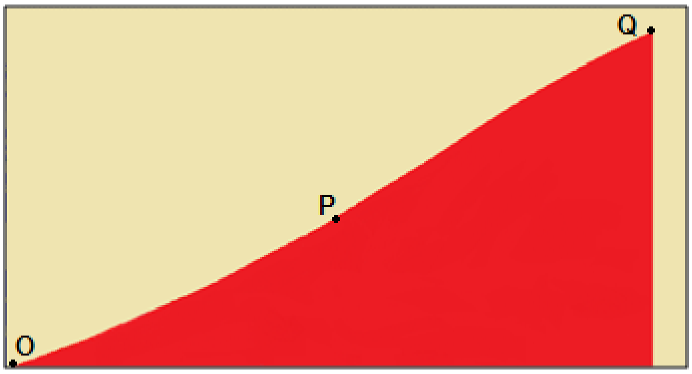

Figure 4.8: Typcial Group A2 stress and strain graph

Figure 4.8 shows a typical Group N2 stress and strain graph. From starting point O to point P the test piece undergoes elastic deformation around the tooth area. At point P to point Q plastic deformation occurs. At point Q the test piece fractures and the test ends.

4.3 Statistical results

4.3.1 Oneway ANOVA analysis

The descriptive statistics of the fracture or maximum load in Newton values for all the test groups are given in Table 4.5. Both Group A1 and Group A2 have significantly higher fracture or maximum load values than Group N1 and Group N2. The ANOVA statistics in Table 4.6 indicate that there is a statistically significant difference between the mean fracture or maximum load in Newton values of the four groups (p-value < 0.001).

Table 4.5: Descriptive statistics of fracture or maximum load in Newton

Group	Number	Mean	Std. deviation	Std. error	95% confidence interval for mean		Minimum	Maximum
					Lower bound	Upper bound		
A1 Control acrylic without diatorics	12	700.2000	747.35094	215.74163	225.3559	1175.0441	214.00	3025.00
A2 Acrylic with diatorics	13	935.5385	157.80242	43.76652	840.1794	1030.8975	633.00	1163.00
N1 Pure nylon material A with diatorics	13	99.2000	21.49093	5.96051	86.2132	112.1868	73.80	138.30
N2 Pure nylon material B with diatorics	13	113.7846	27.24484	7.55636	97.3207	130.2485	65.30	166.80
Total	51	457.5137	516.51709	72.32686	312.2410	602.7865	65.30	3025.00

Table 4.6: ANOVA statistics of fracture or maximum load in Newton

	Sum of squares	df	Mean square	F	P-value
Between groups	6882358.513	3	2294119.504	16.698	0.000
Within groups	6457136.608	47	137385.885		
Total	13339495.120	50			

Multiple comparisons of the dependent variable (fracture or maximum load in Newton) of the test groups were done via the Bonferroni method in Table 4.7. Please note – the mean difference is significant at the 0.05 level.

Table 4.7: Bonferroni multiple comparisons test of the fracture or maximum load in Newton

(I) Experiment	(J) Experiment	Mean difference (I-J)	Std. error	P-value	95% confidence interval	
					Lower bound	Upper bound
A1 (Control) Acrylic without diatorics	A2 Acrylic with diatorics	-235.33846	148.38116	.717	-644.0606	173.3837
	N1 Pure nylon material A with diatorics	601.00000*	148.38116	.001	192.2779	1009.7221
	N2 Pure nylon material B with diatorics	586.41538*	148.38116	.002	177.6932	995.1375
A2 Acrylic with diatorics	A1 Acrylic without diatorics	235.33846	148.38116	.717	-173.3837	644.0606
	N1 Pure nylon material A with diatorics	836.33846*	145.38325	.000	435.8742	1236.8027
	N2 Pure nylon material B with diatorics	821.75385*	145.38325	.000	421.2896	1222.2181
N1 Pure nylon material A with diatorics	A1 Acrylic without diatorics	-601.00000*	148.38116	.001	-1009.7221	-192.2779
	A2 Acrylic with diatorics	-836.33846*	145.38325	.000	-1236.8027	-435.8742
	N2 Pure nylon material B with diatorics	-14.58462	145.38325	1.000	-415.0489	385.8797
N2 Pure nylon material B with diatorics	A1 Acrylic without diatorics	-586.41538*	148.38116	.002	-995.1375	-177.6932
	A2 Acrylic with diatorics	-821.75385*	145.38325	.000	-1222.2181	-421.2896
	N1 Pure nylon material A with diatorics	14.58462	145.38325	1.000	-385.8797	415.0489

This test indicated:

- There is a statistically significant difference in the mean fracture or maximum load in Newton of the A1 control group versus the N1 group, and the A1 control group versus the N2 group.
- There is a statistically significant difference in the mean fracture or maximum load in Newton of the A2 group versus the N1 group, and the A2 group versus the N2 group.

- There is no statistical difference between the two A (acrylic denture base) groups.
- There is no statistical difference between the two N (pure nylon denture base) groups.

The above-mentioned facts can be observed very clearly in the means plots of Figure 4.9.

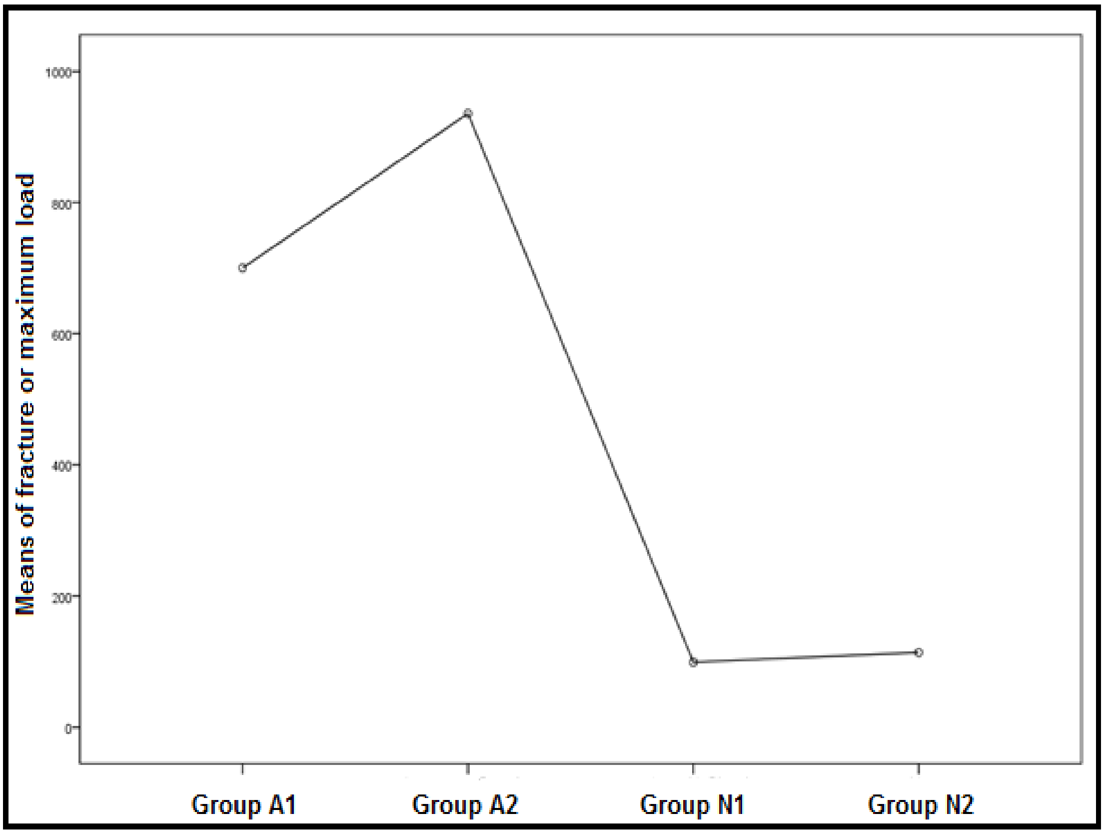

Figure 4.9: Means plots

4.3.2 Chi-square cross-tabulation analysis

Cross-tabulation of the specific area of fracture of the test groups was done in Table 4.8. Due to the scarcity of the data (100% of the cells have expected values less than 5); the Chi-square value was calculated using Fisher's exact test (Table 4.9). The exact p-value is less than 0.001, which shows that there is a statistically significant difference in the area and the way breakage happens between the four experimental groups.

This test indicated:

- Group A1 and A2 have very similar breakage patterns.
- Group N1 and N2 have very similar breakage patterns.
- Group A and Group N have very different breakage patterns respectively.

Table 4.8: Cross-tabulation of specific area of fracture of groups

			Group				
			A1 Control	A2 Acrylic with diatorics	N1 Pure nylon material A with diatorics	N2 Pure nylon material B with diatorics	Total
Specific area of fracture	Acrylic below tooth – adhesive	Count	3	4	0	0	7
		% within experiment	23.1%	30.8%	0.0%	0.0%	13.5%
	Facial third of acrylic tooth – adhesive	Count	2	0	0	0	2
		% within experiment	15.4%	0.0%	0.0%	0.0%	3.8%
	Facial third of acrylic tooth – slightly cohesive mesially	Count	2	0	0	0	2
		% within experiment	15.4%	0.0%	0.0%	0.0%	3.8%
	Facial third of acrylic tooth – slightly cohesive mesiodistally	Count	4	0	0	0	4
		% within experiment	30.8%	0.0%	0.0%	0.0%	7.7%
	Facial third of acrylic tooth – slightly cohesive mesiodistally, along mesiodistal arm of diatoric T	Count	0	2	0	0	2
		% within experiment	0.0%	15.4%	0.0%	0.0%	3.8%
	One long fracture: along acrylic below tooth through facial third of tooth – cohesive mesiodistally	Count	0	1	0	0	1
		% within experiment	0.0%	7.7%	0.0%	0.0%	1.9%
	Snapping and failure of nylon at mesiodistal diatoric exits on teeth	Count	0	0	0	13	13
		% within experiment	0.0%	0.0%	0.0%	100.0%	25.0%
	Stretching and failure of nylon at mesiodistal diatoric exits on teeth	Count	0	0	13	0	13
		% within experiment	0.0%	0.0%	100.0%	0.0%	25.0%
	Two fractures: acrylic below tooth – adhesive/facial third of acrylic tooth – adhesive	Count	1	0	0	0	1
		% within experiment	7.7%	0.0%	0.0%	0.0%	1.9%
	Two fractures: acrylic below tooth – adhesive/facial third of acrylic tooth – adhesive, very shallow	Count	0	3	0	0	3
		% within experiment	0.0%	23.1%	0.0%	0.0%	5.8%
	Two fractures: acrylic below tooth – adhesive/facial third of acrylic tooth – slightly cohesive mesially	Count	1	3	0	0	4
		% within experiment	7.7%	23.1%	0.0%	0.0%	7.7%
Total		Count	13	13	13	13	52
		% within experiment	100.0%	100.0%	100.0%	100.0%	100.0%

Table 4.9: Chi-square tests

	Value	df	Exact p-value. (2-sided)
Pearson Chi-square	136.286[a]	30	0.000
N of valid cases	52		

a. 44 cells (100.0%) have expected count less than 5. The minimum expected count is .25.
b. The standardised statistic is 3.033.

4.4 Limitations of the study and possible further studies

4.4.1 Laboratory study

The experiments for this research were done on a machine that produces the same amount of load at a preset increase for a relatively short period of time on the test pieces. The clinical environment differs in that it applies dynamic loads to the denture teeth over the extended period of denture wear. Thus the results of this study should be deemed exploratory and further clinical studies should ensue to prove or disprove the findings of this study.

4.4.2 Testing technique

There is no standardised test for determining the retention of acrylic denture teeth in pure nylon denture base materials. In this study standard tests for the retention of acrylic denture teeth in acrylic denture base materials was modified to suit the needs of the research to be done. Therefore the results of this study should be deemed exploratory and it is recommended that further development of a standard test, especially for acrylic denture teeth in pure nylon denture base materials, should be done.

4.4.3 Testing materials

Only one kind of acrylic denture base material (Vertrex Rapid Simplified), two kinds of pure nylon denture base materials (Valplast and Perflex Flexi Nylon) and one kind of acrylic tooth (Vita MFT) were used during this study. Other materials could possibly be used in a separate study of the same nature to verify or disprove the findings of this study.

4.4.4 Test result deviations

In this study it was ensured that all test pieces were identical. Highly accurate test piece duplication was done through the use of silicone, one kettle of molten wax was used during test piece construction, and the same tooth mould was used for all test pieces constructed. Despite this, there was still considerable deviation within the results of each test group. It is suspected that the multiple surfaces involved in accommodating the diatorics in the tooth structure and denture base materials might be responsible for this large deviation. More investigation is needed in this regard.

CHAPTER FIVE
CONCLUSION AND RECOMENDATIONS

5.1 Introduction

The purpose of this study was to compare the retention of acrylic denture teeth in pure nylon dentures to that of teeth in conventional acrylic denture bases (the acrylic test pieces serving as the control standard). A further purpose was to explore whether creating diatorics in acrylic teeth for use with pure nylon denture bases potentially has a weakening effect on the tooth structure.

5.2 The retention of acrylic denture teeth in pure nylon denture bases compared to those in conventional acrylic denture bases

The statistical research shows that the mechanical retention of acrylic denture teeth in pure nylon denture bases is inferior to the mechanical and chemical retention of acrylic denture teeth in acrylic denture bases. There is a statistically significant difference in the mean fracture or maximum load in Newton of Group A versus Group N (see section 4.3.1).

During testing of the pure nylon denture base pieces it was evident that the weakest point of the pure nylon denture base material's mechanical retention lies at the mesial and distal diatoric exits on the teeth. Failure of the pure nylon denture base material occurred at the mesial and distal diatoric exits on the teeth without exception in every test piece within Group N.

The hypothesis that the bond strength of acrylic teeth onto a pure nylon denture base will be less than that of acrylic teeth onto a conventional acrylic denture base was correct.

5.3 The influence of the diatorics on the tooth structure

Group A1 served as the control standard during this study. As in conventional practice, it consists of an acrylic denture base material and acrylic teeth without diatorics. Group A2 consisted of the same acrylic denture base material and acrylic teeth with diatorics. During testing no statistical difference in the mean fracture load in Newton was found between the two A groups. Since the only difference between the two groups is the diatorics, this would indicate that when the diatorics are created as prescribed within the tooth, the tooth structure is not weakened.

As for the specific area of breakage of the test pieces, the Chi-square cross-tabulation analysis indicated that the A groups have very similar breakage patterns. More fractures in the diatoric area of the A2 group would have indicated that the diatoric T weakens the tooth structure: Group A2 did not fracture more in the diatoric area than Group A1, which leads to the conclusion that when the diatorics are created as prescribed within the tooth, it does not weaken the tooth structure.

In respect of the N Group: with the pure nylon denture base material breaking off at the mesial and distal diatoric T exits on the teeth without exception, the tooth structure itself seems to be safe from any influence that drilling the diatoric T into the teeth could have, as the mechanical retention at the mesial and distal diatoric T exits always fails first.

The hypothesis that diatorics should not influence the acrylic tooth structure detrimentally if created as prescribed is therefore correct.

5.4 Recommendations

5.4.1 Clinical testing

This study differs from the clinical situation in four very important ways. It lacked supporting teeth; the tooth angulation was over exaggerated; the whole tooth structure was used (which is not always possible in the clinical situation); and, load application (see section 4.1).

In my personal experience of creating nylon dentures over the past few years, I have only encountered two mechanical retention denture tooth failures. They were both on single anterior tooth nylon dentures with limited mesiodistal space. In both cases the retention failed in the mesial and distal diatoric T exit areas, exactly as described in the research undertaken in this study.

In my experience with nylon dentures, I am of the opinion that although mechanical retention failure of teeth in nylon dentures do occur, it does not do so at the rate that this laboratory study would lead us to believe.

I therefore recommended that clinical testing be done to either verify or disprove the conclusions of this study.

5.4.2 Diatoric T design

As this study has identified that the pure nylon denture base material has a weak point on the mesial and distal diatoric T exits on the teeth, further investigation into the design of the diatorics created for mechanical retention of acrylic teeth onto a pure nylon denture base is needed.

In my own work experience I have found that the diatoric T design provides enough retention for posterior teeth. However the shearing forces applied on the anterior denture teeth, while biting, puts a significant amount of stress on the mechanical retention provided by the diatoric T design. To help counter these stresses the amount of tooth neck area covered with nylon was increased. This creates more resistance against these forces. It was also found that if an extra diatoric on the palatal surface of the anterior tooth which joins to the centre of the diatoric T design was created, the mechanical retentional strength increases considerably.

This new design would require further investigation..

5.4.3 Further material development

Further development of pure nylon denture base material is needed to ensure a better retention of acrylic denture teeth within the pure nylon denture base material.

It would be most advantageous if some form of chemical retention could be gained alongside the mechanical retention in order to retain denture teeth better in nylon dentures. In the past, nylon denture base material manufacturers have opted to include methyl methacrylate in the flexible nylon denture base material mix in order to gain chemical retention. The inclusion of this chemical has however had a negative influence on the flexibility and strength properties of the nylon.

An alternative solution will have to be considered to ensure the longevity of flexible nylon dentures.

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APPENDIX A

Specifications of materials used

Material name and manufacturer	Material lot number and certification	Manufacturer's instructions for usage
Wax Metrowax no.4 by Metrodent	Lot no. 260 2013 CE	Wax melting range 80˚C–-85˚C
Acrylic denture base material Rapid simplified heat curing denture base material by Vertex	Monomer lot no. XW243L27 Polymer lot no. XU091P04 CE 0197 PCT NM05 ISO 1567 type 1 class 1	Mixing ratio 1ml liquid to 2,3g polymer. Dough time 15min Working time 30min Curing time 20min at 100˚C
Duplicating silicone NV-Sil by Neirynck and Vogt N.V.	Component A lot no. 12073 Component B lot no. 12074 PCT	Mixing ratio 1:1. Mixing time 40sec. Working time 5min Setting time 30sec.
Plaster Dental plaster by Saint Gobain	Lot no. 15:02 10/11/12	Mixing ratio 100/60 by weight Initial setting 10min Final setting 30min
Yellow stone KD Dentstone by Saint Gobain	Lot no. 18:54 18/03/13	Mixing ratio 100/30 by weight Initial setting 11min Final setting 45min
Lab putty Lab putty hard by Coltène	Base lot no. F21969 Activator lot no. F15679 ISO 4823	Mixing Ratio 11g base to 0.3g activator. Mixing time 30–45sec. Working time ca. 90sec. Setting time 5–7min
Rubber-based glue Val-Cement by Valplast	Lot no. 20214 CE	Use bamboo applicator to apply a small amount of Val-Cement to the stone surface of the flask after boil-out. Place artificial tooth in place and let dry.
Pure nylon denture base material A Valplast standard pink by Valplast	Lot no. 130143 CE 0470	Heating time 11min at 550˚F Pressure after casting 3min Cool down period 20min
Pure nylon denture base material B Flexinylon standard pink by Perflex	Lot no. 1700CC CE CA010953	Heating time 11min at 550˚F Pressure after casting 5min Cool down period 20min
Acrylic teeth MFT mould R45 colour 2M2 by Vita	Lot no. D6 CE 0124	Multifunctional teeth for centralised or lingualised occlusion