# THE PERFORMANCE OF BASE METAL CERAMIC ALLOY RESTORATIONS WITH REFERENCE TO VARIANCES IN THICKNESS IN METAL AND PORCELAIN IN ORDER TO ESTABLISH OPTIMAL THICKNESS RATIOS TO MAXIMIZE STRENGTH AND AESTHETIC CHARACTERISTICS

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# DEDICATION

This study is dedicated to:

My Lord and Saviour, Jesus Christ, who sustained me through personally trying times during the time of this study.

The greatest problem in maximizing strength and aesthetic characteristics of metal ceramic restorations arises when there is a lack of available space to allow sufficient thickness of metal alloy and porcelain. This generally results in the metal alloy being reduced to its minimum to allow adequate porcelain thickness. The minimum thickness to which noble metal alloys can safely be reduced, is generally accepted to be 0.3 mm due to previous clinical time-dependent trial and error. Agreement regarding the minimum thickness to which base metal alloys can safely be reduced is still under dispute possibly because base metal alloys have not had the same duration of clinical exposure.

The objectives of the present study were:

1. To determine the influence thickness variations of the base metal alloy would have on strength characteristics of metal ceramic restorations and thereby establishing the minimum thickness to which base metal alloys can safely be reduced.
2. To determine the influence thickness variations of porcelain would have on strength and aesthetic characteristics of metal ceramic restorations and thereby establish the minimum thickness to which the porcelain thickness can safely be reduced.
3. To determine which base metal alloy to porcelain thickness ratios would be most suited in order to maximize strength and aesthetic characteristics in metal ceramic restorations where the amounts of available space for the alloy and porcelain are varied.

For objective (1) Tensile strength tests to determine and compare the ability of various alloy thickness to resist porcelain fracture were performed in Newtons. For objective (2) Tensile tests to determine and compare the ability of various porcelain thickness to resist porcelain fracture were performed in Newtons.

For objective (3) The results from objective (1) and (2) were integrated and compared in order to reach the final goals of this study. These results were compared to a Noble metal alloy control group to indicate clinical acceptable strength values.

Evaluation of the tensile test results showed the following:

1. Reducing the base metal alloy thickness to 0.1 mm or below was not recommended. Distortion of these thin sample after sandblasting and porcelain firing respectively also indicated possible manufacturing problems.
2. Reducing the porcelain thickness to below 1.0 mm was not recommended due to unacceptable strength and aesthetics
3. The minimum thickness ratios that were acceptable were the 0.2 mm base metal thickness combined with 1.0 mm porcelain thickness.

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# CHAPTER ONE

## *THE PROBLEM AND ITS SETTING*

### 1.0 INTRODUCTION

Previous research efforts regarding metal ceramics have concentrated on improving properties of metal alloys and porcelain, thereby improving the overall properties of metal ceramic restorations in dentistry (Anusavice, 1996:585-617). From these studies information on the properties of porcelain derived from various tests, such as establishing modulus of rupture, biaxial compressive strengths and tensile strengths, as well as methods to strengthen porcelain was obtained. However, despite the proliferation of knowledge about these properties of porcelain and metal alloy, no known accurate predictions could be made regarding their performance when porcelain and metal alloy thickness ratios were varied indiscriminately during crown or bridge construction using metal ceramics.

Recent research involving ceramics includes:

1. Analysis of tempering stresses in metal ceramic disks involving tempering of the porcelain material (De Hoff *et al.*, 1996).
2. Microcracks in porcelain and their behaviour during multiple firing (Mackert and Williams, 1996).
3. Effects of flaw size and auto-glaze treatment on porcelain strength (Griggs *et al.*, 1996).
4. Effect of cubic leucite stabilization on flexural strength of feldspathic dental porcelain (Dentry *et al.*, 1996).
5. Comparative strength of porous porcelain materials (Mack *et al.*, 1997).

All the above studies focused on the strength of porcelain by modifying the crystalline structure, but did not solve the practical problems experienced by the laboratory technologists regarding the strength characteristics when using variations of thickness of metal and porcelain once these are bonded together.

Accurate predictions about strength characteristics, especially for base metal ceramic restorations, were still not possible at the time of this study. However, it is envisaged that the outcome of this study should be of benefit to students doing research into metal ceramics, as well as to qualified dental technologists and dentists. The technologist will thus be able to design restorations of a higher quality where a compromise between aesthetics and strength is required. In collaboration with the dentist, a better understanding of design principles involved in a dental laboratory and the depth of preparation required to optimize strength and aesthetic properties of restorations may be realized. This is vital in the light of the growing demand for knowledge in the field of dental technology that is ever-increasing in application.

Benefits of this study will:

1. Allow for criteria for base metal ceramics in order to maximize strength and aesthetics.
2. Establish safety margins where lack of space prevails.
3. Lead to a broader understanding of factors contributing to strength of metal ceramics.
4. Enhance confidence in the technologist in using cheaper base metal alloys, hopefully resulting in huge savings to the consumer.
5. Lead to a broader understanding of the factors contributing to aesthetics of metal ceramics.

## 1.1 STATEMENT OF THE PROBLEM

The purpose of this investigation was to investigate the performance of base metal alloy ceramic restorations with reference to variations in thickness in metal and porcelain in order to establish criteria to maximize the strength and aesthetics (according to thickness requirements to match a shade) in restorations.

## 1.2 STATEMENT OF THE SUB-PROBLEMS

### *1.2.1 Sub-problem One*

The first sub-problem was to investigate the performance of base metal ceramic restorations with reference to variation in thickness in metal in terms of strength, in order to establish strength characteristics of metal alloys in restorations.

### *1.2.2 Sub-problem Two*

The second sub-problem was to investigate the performance of base metal ceramic restorations with reference to variations in thickness in porcelain in terms of strength and aesthetics (according to thickness requirements to match a shade) in order to establish strength and aesthetic characteristics of porcelain in restorations.

### *1.2.3 Sub-problem Three*

The third sub-problem was to integrate strength characteristics of metal with strength and aesthetic characteristics of porcelain in order to establish criteria to maximize strength and aesthetic (according to thickness requirements to match a shade) characteristics in restorations.

## 1.3 HYPOTHESES

### *1.3.1 Hypothesis One*

It was hypothesized that a linear relationship existed between metal alloy thickness and the force required to fracture the metal alloy/ ceramic combination, and that the critical force value needed to fracture the porcelain could be identified for each metal alloy thickness.

### *1.3.2 Hypothesis Two*

It was hypothesized that a linear relationship existed between porcelain thickness and the force required to fracture the porcelain, and that the critical force value needed to fracture porcelain could be identified for each thickness of porcelain.

### *1.3.3 Hypothesis three*

It was hypothesized that the knowledge of the nature of fracture patterns for porcelain would set the basis for formulating predictability of metal ceramic restorations to allow maximizing of strength and aesthetic requirements for metal ceramic restorations.

## 1.4 DELIMITATIONS

1. Due to time and budget restraints this study was limited to Wiron 99, (Argen Dental, Johannesburg), base metal alloy. The choice of this base metal alloy was due to its popularity and use and because a beryllium free base metal alloy was required.
2. This study did not evaluate the applicability of the method using beryllium containing base metal alloys, due to the occupational health hazards affecting dental technicians exposed to them.
3. The porcelain of choice used was Creation porcelain (Argen Dental, Johannesburg). Although the properties of feldspathic porcelain are similar for all metal ceramics, this study only utilized one brand.
4. Due to time constraints the design was limited to one specific design that conformed to specific dimensions to which the law of beams applies.

## 1.5 ASSUMPTIONS

Yamamoto (1985:110) indicates that bonding between precious metals consists of 52% chemical, 22% mechanical and 26% compression bonding. Due to the design of test samples, bond strengths were maximized as far as possible. Therefore it was assumed that:

- The major contributing factor toward the bond was the chemical bond component.
- Since recommended procedures for the manufacture of test samples were adhered to, bond strengths remained consistent in each similar group as well as in the physical and chemical properties of the sample materials.
- Results from the design of the samples employed would be of benefit to other designs .
- Due to their increasing use, base metal alloys would play a significant role in the use of metal ceramics in dentistry in the future.
- The clinically acceptable standard for the noble metal alloys could be used as a guide in comparisons with base metal alloys in order to make recommendations for the use of base metal ceramic restorations.

## 1.6 DEFINITION OF TERMS AND CLARIFICATION OF CONCEPTS

### 1.6.1 BASE METAL ALLOY

Base metal alloy refers to nickel-chromium metal ceramic alloys that do not contain beryllium. It must not be confused with cobalt chromium base metal alloys, which do not resist tarnish and corrosion.

### 1.6.2 NOBLE METAL ALLOY

The term noble metal alloys refers to gold platinum based alloys used for metal ceramics. It must not be confused with gold platinum based alloys used for metal crowns, bridges and inlays. Noble metal alloys are indicative of metal elements that resist oxidation, tarnish and corrosion during heating, or soldering and when used intraorally.

### 1.6.3 TENSILE STRENGTH

For the purpose of this study tensile strength is measured at the modulus of rupture of the porcelain during utilization of a three point bending test whereby tensile stress is induced in the porcelain.

### 1.6.4 TENSILE STRESS

Tensile stress refers to the internally induced force that resists the elongation of a material in a direction parallel to the direction of the stress (Van Blarcom, 1999).

### 1.6.5 COMPRESSIVE STRESS

Compressive stress refers to the internally induced force that opposes the shortening of a material in a direction of the stress; any induced force per unit area that resists deformation caused by a load that tends to compress or shorten a body (Van Blarcom, 1999)

### 6.1.6 SHEARING STRESS

Shearing stress refers to the internally induced force that opposes the sliding of one plane on an adjacent plane or the force that resists a twisting action (Van Blarcom, 1999).

### 6.1.7 ALUMINOUS PORCELAIN

Porcelain is classified as Aluminous once it is composed of a glass matrix phase with 35% or more aluminum oxide, by volume (Van Blarcom, 1999).

### 6.1.8 BONDING AGENT

The bonding agent refers to any material used to promote adhesion or cohesion between two different substances (Van Blarcom, 1999).

### 6.1.9 DEFORMATION

Deformation refers to the change of form or shape of an object (Van Blarcom, 1999).

### 6.1.10 MODULUS OF ELASTICITY

In metallurgy, the coefficient found by dividing the unit stress, at any point up to the proportional limit, by its corresponding unit of elongation (tension) or strain. A ratio of stress to strain. As the modulus of elasticity rises, the material becomes more rigid (Van Blarcom, 1999).

### 6.1.11 YIELD STRENGTH

Yield strength refers to the strength at which a small amount of permanent (plastic) strain occurs, usually 0,1 or 0,2% (Van Blarcom, 1999).

6.1.12 TOUGHNESS

Toughness refers to the ability of a material to withstand stresses and strains without breaking (Van Blarcom, 1999).

6.1.13 WARP

Torsional change of shape or outline; to turn or twist out of shape results in warping of the material (Van Blarcom, 1999).

14. NATURAL GLAZE

The production of a glazed surface by the vitrification of the material itself and without addition of other fluxes or glasses results in a natural glaze (Van Blarcom, 1999).

# CHAPTER TWO

## *LITERATURE REVIEW*

### 2.0 INTRODUCTION

The aim of the literature review is to provide the reader with insight into the global difficulties that dentists and dental technicians experience regarding porcelain fracture of metal ceramic restorations, while reaching a compromise between the strength and aesthetic demands of metal ceramic restorations.

The review includes a description of the increasing use and popularity of base metal alloys in dental technology. This includes the metallurgy of base metal alloys with specific regard to Nickel chrome alloys that do not contain beryllium, as well as explanations regarding the health hazards of beryllium to the Dental technician and why its use in base metal alloys should be avoided. As a result it will be noted that the occurrence of beryllium containing alloys is diminishing in practice.

An overview of the problems associated with metal ceramic failure is provided, especially with regard to base metal alloys. The literature review discusses the differences of opinion regarding design principles by different authors in order to ensure success regarding the need to maximize strength and aesthetic characteristics of metal ceramic restorations. This will indicate the need to establish criteria to maximize aesthetics while minimizing the possibility of porcelain fracture.

The properties of porcelain, including the principles of metal-ceramic design factors, with reference to the thickness of the metal alloy and ceramic materials and their influence on the strength of the metal ceramic materials, are also discussed.

The importance of maximizing the metal ceramic bond strength is dealt with, followed by global indications related directly to the problems encountered with the use of base metal ceramic alloys, as well as specific problems that have been encountered locally in the South African commercial environment.

## 2.1 METAL CERAMICS: A GLOBAL ISSUE

Metal ceramic restorations are the most commonly used aesthetic tooth replacement restorations today, due to a conservative approach to dentistry whereby the preservation of existing teeth and tooth structure is advocated as far as possible. The ability to combine the aesthetics of porcelain with the strength and support of the metal alloy substructure to which the porcelain is bonded provides the formula for the success these restorations have contributed to so largely in the evolution of dentistry. This is especially true regarding base metal ceramic alloys (Tucillo and Cascone, 1983:313-337).

In 1964 it was reported that some 35% of all crowns and bridges constructed in the USA were fabricated from porcelain fused to metal (Mumford, 1965). Some seventeen years later the percentage is regarded as being in the order of 95% or above.
Bego catalogue, Germany (undated), indicates that the Wiron 99 base metal alloy is supplied to countries around the world, including South Africa
(Tucillo and Cascone, 1983:313-337).

## 2.2 BASE METAL ALLOYS

Efforts to find less expensive substitutes for the gold, palladium, platinum and silver alloy initially put complications in the way of achieving an acceptable bond between a well-fitting metal casting and an aesthetic ceramic veneer. These problems have however been overcome to such an extent that a significant proportion of the fixed ceramic fused to metal restorations produced in dentistry are now using base metal alloys (Binns, 1983). Today base metal alloys are used more extensively than other metal ceramic alloys, which is due to the sharp rise in cost of noble metal alloys. Base metal alloys are becoming more popular as an alternative metal to noble metal alloys (Anusavice, 1996:424). Dudek (1988:85) also reported that base metal alloys are used more extensively than any other metal alloys. Although mainly due to cost, this is also because of the success experienced when using these alloys, especially for long span bridges.

Personal communication with Mr T. Leach from Nova Dental Suppliers on 19 April 2000, further substantiated that the amount of base metal alloys used for metal ceramic restorations was approximately 95% as compared to about 5% of noble metal alloys.

### *2.1.1 Properties of base metal alloys*

Base metals possess superior properties in that they exhibit a high modulus of elasticity, high tensile strength and a high sag or creep resistance, thus decreasing flexibility significantly and allowing the use of thinner metal sections (Bertolotti, 1988:82).
The main components of Wiron 99, are:
Nickel 65,0; chrome 22,5; molybdenum 9,5; cilium 1,0; niobium 1,0; iron 0,5; cerium 0,5; carbon max 0,02 (Bego catelogue, undated).

According to Bego catalogue (undated) base metal alloys' standard values are :

| | |
|---|---|
| Colour | white |
| Melting interval | 1310-1250°C |
| Casting temperature | 1420°C |
| Density | 8,2g/cm$^2$ |
| Coefficient of expansion 20-600 | 0,000014 |
| Elongation limit (Rp 0.2) | 330 N/mm$^2$ |
| Ductile yield (A 5) | 25% |
| Modulus of elasticity | abt. 205000 N/mm$^2$ |
| Vickers hardness | 180 |

The modulus of elasticity of base metal alloys that is vital for a crown and bridge resistance to stressability is twice as high as with precious metals giving double safety against deformation caused by masticatory forces, and allows for greater bridge span (Bego catalogue, undated).

The bond strength of base metal alloys is excellent and able to stand any critical comparison (Bego Catalogue, undated), and the low thermal conductivity protects the pulp from temperature irritations much better than precious metals (Bego catalogue, undated).

According to Bego, (Bego catalogue, undated) Wiron 99 base metal alloys exhibit extreme corrosion resistance. Noble metal alloys do however exhibit superior corrosive resistant properties and innertness, while base metal alloys produce excess oxide.

This can lead to porcelain discolouration on firing unless the oxide on the base metal alloys is washed away after each firing of porcelain. Base metal alloys need to be cut back sufficiently at the margin to allow a porcelain shoulder that does not show a gray colour around the porcelain margin as this is not aesthetically pleasing, and excess oxide should be washed away after each firing (Personal communication, Marx, 1997).

Studies relating to ion release from base metal alloys by Geis-Gerstorfer *et al.* (1994) reveal a considerable range of corrosion rates among Ni-Cr-Mo alloys of between 0,54 and 3,261 ig/$cm^2$ after 35 days.

Allergic reactions are caused by ion release (an indicator of least stable elements) in patients and must be eliminated for the following reasons:

- A patient who is already sensitized may exhibit reactions as a result of the dissolution of metal in saliva.
- Non-sensitized patients may become sensitized by the alloy. For this reason the alloy must exhibit the lowest possible corrosion rates.
- A nickel uptake exceeding 0,06 mg/L is dangerous in extremely hypersensitive persons.

The following results were obtained in studies using the same base metal alloy as in the present study:

- A high substance loss during the first two days of passivation was evident but then decreased.
- After 35 days the ion release reached a mean total value of 47,3 ig/$cm^2$. The total ion release is estimated at 40,1 ig/$cm^2$ for nickel and 0,9 ig/$cm^2$ for iron after a year, although passivation seems to reduce ion and nickel release to acceptable levels for persons not very nickel sensitive, if the alloy is not disturbed (Geis Gerstorfer *et al.*, 1994).

Moffa *et al.* (1984:491) found with *in vitro* studies comparing base metal alloys to a gold metal alloy, that after three months the base metal alloys did not cause gingival inflammation. However, after five years the base metal alloys appeared to show evidence of approximately twice the incidence of inflammation as the gold alloy, but the differences were not statistically significant. They further indicated that the performance of base metal alloys on the basis of composition and properties was different from one another. However, this study was restricted in that it dealt with one base metal alloy only.

Moffa *et al.* (1984) also found that with special regard to the porcelain veneer performance, certain base metal alloys performed just as well as the gold alloy, while others, although also mainly of nickel chrome composition, indicated a higher rate of porcelain to metal bond failure. The main difference between the better performing alloy and the poorer performer was the inclusion of beryllium, which improved properties of fluidity, castability and strength. However, beryllium has been proven to be harmful to the dental technician working with it, and as a result there has been an effort to move to beryllium-free base metal alloys.

By excluding patients known to be sensitive to nickel, Moffa *et al.* (1984) reported no incidence of nickel sensitivity in patients using base metal alloys after five years when the patch test was applied. They concluded that the base metal containing beryllium had no significant difference when compared with the performance of gold alloys, but that other base metal alloys without beryllium resulted in differences regarding tarnish, corrosion and fractures of porcelain veneers.

Strietzel (Bego information brochure, undated) indicates, in an article entitled "The Nickel Misconception", that it is in fact not the amount of nickel, but the quantity of chromium that is responsible for the release of nickel through the corrosion process.

If the chromium content is below 15% an increased ion release in all alloy components will result since the passivation due to chromium content will not be sufficient. Hence an increase in beryllium leads to increased ion release. Nickel-chromium alloys with a chromium content above 20% can be regarded as mouth-resistant (Strietzel, Bego information brochure, undated).

In reviewing the related information from the above studies it was evident that base metal alloys must be selected carefully, as not all base metal alloys provide acceptable properties. Moreover, base metal alloys that contain beryllium must particularly be avoided since they may pose particular health hazards to the operating technician. However, there are many base metal alloys that produce excellent properties that are superior even to noble metal alloys with respect to modulus of elasticity and yield strength. Though their corrosion resistance is not as good as that of noble metal alloys, certain base metal alloys do exhibit a good resistance to tarnish and corrosion.

Without the use of base metal alloys the use of long span bridges would be restricted. It has become evident from sales figures that the use of base metal alloys, has become an integral part of modern dentistry, and is unavoidable. However, the extensive use of base metal alloys in single units and smaller span bridges should be avoided where possible, as noble metal alloys possess better qualities of inertness and prevention of long term inflammation.

## 2.3 METAL CERAMICS: AN OVERVIEW

The two major components responsible for the strength of metal ceramic restorations are the metal alloy framework and the porcelain.

The metal alloy framework would resist most of a load due to the occlusal force applied to the metal ceramic assembly. This indicates that the thicker the metal the stronger the metal ceramic assembly will be (Yamamoto, 1985:23). However, 1mm depth in porcelain is the minimum for aesthetic requirements of translucency and depth in colour in order to prevent an opaque look (Kersten, 1988:383).

The problem is that the demand for porcelain thickness has resulted in the necessity to reduce the thickness and support of the alloy substructure, therefore a compromise between strength and aesthetic requirements is often necessary. Another factor that compounds the problem is that the demand for conservative dentistry often results in insufficient tooth reduction, in order to allow sufficient insulation and to protect the pulp. As a result the dental technician is forced to reduce the metal alloy coping as far as possible, in order to maximize the natural aesthetics of the porcelain (Kersten, 1988:383-387).

According to Yamamoto (1985:50) ideal tooth reductions are:
1,2 mm at the marginal preparation, 1,5 mm along the sides, and 2,0 mm incisal or occlusally. However, since a dental laboratory may contract work from various dentists, the amount of tooth reduction tends to vary considerably from the more common conservative approach to an over reduction of tooth surface, especially where root canal therapy has been performed.

These fluctuations in the amount of tooth reduction indicate a need to vary the ratio of metal alloy to porcelain thickness as well as alloy thickness considerably. This results in changes in the aesthetic and strength properties of different restorations.

Porcelain is hard, brittle and fragile; it would crack and separate as soon as the framework becomes deformed.

As a result porcelain on its own cannot withstand deformation at all as this will result in cracking. However, when fusing a brittle porcelain that is very weak in shear resistance to forces onto a metal substrate that might easily be bent by finger pressure alone, the result is a reinforced product whose strength is much greater than the combination of the two separate materials when tested individually (Yamamoto, 1985:20).

Porcelain, as a dental material, contains microcracks which propagate during deformation resulting in failure (Dentry *et al.,* 1996). However, porcelain, although weaker in nature, also supplies strength to the restoration (Halloway *et al.,* 1997). Due to the reinforcing nature of the porcelain-metal assembly, the restoration exhibits greater strength than porcelain or metal individually, resulting in a synergistic structure due to the bond interface. This has been a great contributing factor to the success of the metal ceramic restoration, since the bond interface reduces the amount of flaws at the surface, strengthening the porcelain material considerably. Yamamoto (1985:21) illustrated this effect by fusing a 0,7 mm thickness of porcelain to a metal alloy sheet of the following dimensions: 0,3 mm thick, 6.0mm wide and 15.0mm long. The combined metal alloy and ceramic assembly resisted a 25kg load without fracturing. This illustrated the synergistic effect of porcelain and metal bonding, and showed, according to Yamamoto (1985:21), that once fused to the metal alloy, porcelain can deform significantly without fracturing even to the extent that it is obvious to the naked eye. This would not be possible for porcelain on its own at all.

A recent study indicated that the loads required to fracture metal ceramic restorations with a porcelain margin were greater when compared to restorations with a metal margin, indicating the influence of porcelain strength relative to its own thickness (Gardner *et al.*, 1997). This shows that the strength of porcelain does not rely only on the thickness of the metal framework alone, but also on the thickness of porcelain and the quality of the metal ceramic bond.

An earlier investigation substantiating the influence of the bond interface showed that platinum foil of 25um thickness bonded to the porcelain increased the strength of porcelain by as much as 83% (Mclean, 1980:172). Since such a thin metal substructure has very little strength, the increase in porcelain strength must be attributed to the metal ceramic bond interface, rather than to the metal substructure..

The metal ceramic bond prevents microcracks in porcelain from enlarging and propagating further, thereby allowing porcelain to have a strength closer to the theoretical value of glass. This is because the strength of glass is decreased by small flaws called Griffiths flaws that cannot be prevented unless glass is formed in such a thin fiber that flaws have no space to exist (Yamamoto, 1985:15).

### *2.3.1 Properties of porcelain*

According to Claus and Rauter (undated) porcelain consists mainly of the following elements:

| | |
|---|---|
| Feldspar | 70-80% |
| Quarz | 10-30% |
| Kaolin | 0-3% |

Dental porcelain is characterized by a feldspar agent, the leucite crystal. It consists predominantly of a glassy matrix with leucite crystals embedded in it. Orthoclase, a potash feldspar and the main raw material constituents of dental porcelain are responsible for the leucite crystal formation during fusion, which in turn is responsible for the structural stability of dental porcelain. The crystallization of dental porcelain on firing takes place randomly and is influenced by the shape that the particles have been molded into as well as how closely they are compacted together. To appreciate the importance of leucite in maintaining the structure of previous modeling, comparisons can be made of porcelain to glass that runs to such an extent when molten that any previous modeling disappears.

Glass melts into a clear transparent fluid and does not form leucite crystallization (Claus and Rauter, undated brochure).

The fusion curve of dental porcelain may run from 1170 to 1125°C, but only after 1540°C will the leucite dissolve into a melt. This temperature range indicates the wide firing interval of dental porcelain. Leucite exists as allotropes in the cubic (or isometric) and tetragonal crystal forms, and is found in nature often in beautiful cubic crystal forms (Claus and Rauter, undated brochure).

The success of metal ceramics relies on matching the coefficient of thermal expansion of the porcelain and the alloy, and producing a good porcelain-to-alloy bond. This will be dealt with further under factors influencing bond strength.(Claus and Rauter, undated brochure). The significance of the role of coefficient of thermal expansion is important with regard to the metal. The metal alloy may be cast to a homogenous consistency; however, it is very difficult to maintain a homogenous structure for porcelain, even though only the purest ingredients are used in order to get consistent results, especially regarding the coefficient of thermal expansion (Anusavice, 1996:586-590).

The following highlight some of the more important factors influencing homogeneity that may in turn influence the strength of the material:

1. Griffiths flaws - which can be defined as small surface flaws found in porcelain.
2. The use of different layers of porcelain for aesthetics.
3. Variations in coefficient of thermal expansion.
4. Factors influencing the crystalline structure formation.
5. Condensation and application techniques.
6. Final glazing, and surface texture.
7. Design variations.
8. Composition and particle size.

These factors are indications as to why porcelain does not always perform consistently.

### *2.3.2 Strength of porcelain*

The strength of porcelain has always been seen as a limitation, especially regarding tensile strengths. However, there are methods that may be utilized to influence the strength of porcelain. According to Anusavice (1996:590-595) there are two methods of strengthening dental porcelain materials:

1. Interruption of crack propagation through the material, and
2. Introduction of residual compressive stresses into the surface of the material.

The first involves the incorporation of alumina, or stabilized zirconia as components added to the feldspar base porcelain to strengthen it. This however influences the translucency and aesthetics negatively and is used mainly for all ceramic porcelain cores, an aspect which is not dealt with in this study.

The second involves several methods. Two methods relating to this study and the metal ceramic technique will be discussed briefly, before going on to design criteria involving a metal alloy substructure.

1. Thermal tempering

Thermal tempering is a process that creates residual surface compressive stresses by rapid cooling of the object while it is still in a softened molten state. This results in the outer surface cooling first and the molten inner core shrinking last, leaving the inner core in a state of tension and residual compressive stresses on the outer surface. This minimizes flaws and their possible further propagation into cracks.

Such strengthening relies on allowing the metal ceramic assembly to cool rapidly as soon as the firing cycle has been completed (Anusavice, 1996:590-595).

Slow cooling is not recommended unless over-compression of the porcelain at the surface results due to design, such as in the case of a pontic that is completely covered by porcelain. However, cooling rates influence the coefficients of thermal expansion of the metal alloy and porcelain, and recommended firing cycles and cooling cycles should be employed (Yamamoto, 1985:185-188).

2. Coefficient of thermal expansion mismatch

Thermal expansion coefficient mismatch, whereby the inner mass of material may possess a higher coefficient of thermal expansion, thus shrinking more as the object is cooled than the outer layer, will also introduce residual compressive stresses on the outer surface. The outer more translucent porcelains thus normally have a lower coefficient of thermal expansion.

The metal and porcelain must also conform to the manufacturer's specifications regarding coefficient of thermal expansion with that of the metal being slightly higher (Yamamoto, 1985:158-162).

### *2.3.3 Aesthetics of porcelain*

The leucite crystals and the firing process that influences their formation are additional factors that affect the aesthetics of porcelain.

Correct sintering and amount of crystallization result in the correct amount of light being refracted, diffracted and reflected from the surface and internal structure of the ceramic crown. This allows an accurate reproduction by porcelain of the natural tooth structure being replaced (Preston, 1983:511).

If the porcelain is under-fired, over-crystallization will tend to prevent the desired amount of translucency of the porcelain. This occurs if the porcelain is held a long time at the leucite crystal forming temperature range and not allowed to reach the final sintering temperature required (Yamamoto, 1985:177-181).

If the porcelain is over-fired, it melts into a glassy phase that prevents the required refraction and diffraction, possibly resulting in more light being reflected. The porcelain tends to defitrify which results in a milky white appearance and the loss of the correct shade selected. This happens when porcelain is fired at too high a final temperature, or is exposed to too many firing cycles ( Yamamoto, 1985:177-181).

## 2.4. DESIGN CRITERIA

Although metal ceramic bridges are not symmetrically shaped exactly like a beam, the laws applied to beams still apply when a force is applied.

According to Shillingburg (1997:93-97), the following factors apply:

- The flexure of the bridge increases proportionally to the cube of the increase in the length of the bridge. In other words if the length is doubled the flexure will be 8 times greater and if it is 3 times as long it will flex 27 times more. The greatest area of significance is the connectors which are the thinnest part of a bridge and therefore the weakest link or area where flexure or failure will occur.

- The flexure is also inversely proportional to the cube of the height of the connectors. Thus if the height or thickness is halved the flexure will again be 8 times greater.

- The flexure increases proportionally to the inverse of the width of the bridge connectors. Thus by halving the width the flexure will double. This is significant because as soon as the bridge flexes past the critical strain value of 0,1%, the porcelain will crack.

Literature poses uncertainty as to how much the base metal alloy may be reduced in thickness when compared to noble metal alloys. Yamamoto (1985:24) suggests that base metal alloys can safely have a minimal thickness of 2.92mm, when using Young's formula. In contrast, Weiss (1983:232) suggests that base metal alloys may be reduced to 0,1 mm.

In practice, base metal alloy thickness is reduced to 0,1 mm with no certainty about the long-term consequences. These may result in possible time delayed fractures, due to occlusal loading (Takeshita *et al.,* 1997). This is because in reaching a compromise between strength and aesthetics, the metal ceramist is often forced to reduce the base metal alloy thickness to its lowest limit (Kersten, 1988:383).

Yamamoto (1985:189-190) sets the maximum perimeters for porcelain and recommends that the thickness of porcelain should not exceed 2,0 mm as tension prevails in the areas thicker than 2mm because compression ranges for porcelain lie within the 2,0 mm range. As a result Yamamoto (1985:189-190) recommends that preparation designs for crowns include a reduction of 2,0 mm at the incisal or occlusal surface; 1,5 mm at labial and lingual surfaces and inter proximally and 1,2 mm towards the margin. These ideal preparations are seldom found in the commercial environment and generally the crown and bridge technician has to reach a compromise between strength and aesthetics because of a lack of available space.

According to Kersten (1988:323-387) the dental technologist's most common complaint has always been the lack of space for porcelain to achieve the desired shade match; and at least 1,0 mm of porcelain is necessary to match most shades.

The correct preparation designs must be adhered to so that sufficient space for alloy and porcelain depths will be met. This will ensure that strength and aesthetic demands are met in all areas except the margins. The margins tend to need special preparation attention as there is inevitably a thinner finishing section (Yamamoto, 1985:495-499).

Not adhering to proper preparation techniques whereby enough space is created results in a reduction of either alloy or porcelain or both to the extent that either the strength or aesthetics or both strength and aesthetics are negatively affected. The question is always how thin can the base metal alloy be made and still allow for successful metal ceramic restorations (Weiss, 1977).

According to Weiss (1977), clinically acceptable parameters for gold alloys have been fine-tuned, due to decades of use resulting in the following dimensional parameters:

| | | |
|---|---|---|
| Coping Thickness | Single unit | 0,33 mm |
| | Multiple units | 0,4 to 0,5 mm |
| Connection area and lingual collars | Single unit | 2,0 to 3,0 mm |
| | Multiple units | 3,0 to 4,0 mm |

These minimum dimensions represent the composite of major manufacture specifications to resist forces generated during occlusal function.

After a clinical study covering a period of eight years and including 4 500 units of base metal alloys, Weiss (1977) submitted the following dimensional parameters for an unmodified Nickel-chromium alloy:

| | | |
|---|---|---|
| Coping Thickness | Single unit | 0,1 to 0,2 mm |
| | Multiple units | 0,2 mm |
| Connection area and lingual collars | Single unit | 0,0 to 1,0 mm |
| | Multiple units | 1,0 mm to 2.5mm |

The values for premium ceramic gold continue to be near the lower limit of strength as a metal ceramic alloy and are indicated only for short-span bridges and single units even when the thicker noble metal alloy thickness parameters are followed. However, base metal alloys can be successfully utilized for long-span bridges.

This is because all Nickel-chromium alloys exhibit a modulus of elasticity greater than all other metal ceramic alloys and fall roughly into two categories:

1. Those of yield points at or below noble metal alloys, and
2. Those of yield points substantially higher.

The first are modifications designed to improve the working characteristics. However, this jeopardizes the most important property of strength. Using proper techniques, the base metal alloys cast as accurately as gold alloys, produce superior sag resistance, and allow facial collars to be finished to inconspicuous dimensions (Weiss, 1977).

Even though previous research has supported the use of base metal alloys extensively, dental technicians are not confident to make base metal alloys as thin as 0,1 to 0,2 mm. More recent publications have indicated that copings should be around the 0,3 mm thickness for base metal alloys (Yamamoto, 1985:24). This debate has resulted in the need for this study to determine confidence levels in using base metal alloys to the recommended optimum thickness of metal substructures.

Another factor regarding metal ceramic strength is that varying thickness of porcelain plays a significant role regarding thickness to which the metal alloy may be reduced (Yamamoto, 1985:25-42). This indicates the need for further research as to whether coping of base metal alloys can be reduced to 0,1 mm routinely.

Certain recommendations and guidelines regarding design criteria have been established with regard to the properties of porcelain in order to prevent porcelain fracture.
Binns (1983:128) indicates that the critical strain in the order of 0.1% is the limiting factor for dental ceramics, whether bonded to a metal alloy or not.

According to Binns (1983:35) the following limitations to the strength of porcelain apply:

1. Strength of dental ceramics depends on the fabrication defects and internal and surface flaw size and number. Porosity of up to 5% of a spherical nature has little influence on decreasing strength; however, porosity at a metal alloy porcelain bond interface will have a significant effect on the strength of the unit.
2. Static fatigue may operate and cause propagation of fractures at low levels of stress in a moist environment, due to stress enhanced chemical reactions between water and the ceramic at the crack tip.
3. Bulk of ceramics possibly due to space constraints results in thinner porcelain sections being more flexible and reaching the 0,1% critical strain value move readily.
4. Crystalline materials that strengthen ceramics are more opaque resulting in translucent ceramic material of less strength being used due to their desired aesthetics.

According to Yamamoto (1985:19-73) the following design factors must be considered to prevent the above mentioned problems and allow a translucent feldspathic porcelain to be strengthened by design principles:

- Full porcelain coverage of metal, which allows for an even distribution of stresses in the porcelain, is desirable.
- Metal alloy surfaces must be smooth and rounded, with as large a radius of curvature as possible, to allow for even shrinkage of porcelain, which in turn minimizes stresses due to sharp corners or re-entrant angles.

- The metal framework must be designed in such a way that an even thickness of porcelain is supported. At least 1,0 mm of porcelain is desirable though not always possible. However, not more than 2,0 mm of porcelain should be supported since any bulk amount thicker than this will result in shear and eventually tensile stresses being incorporated into the porcelain, which will be much weaker and prone to fracture, since desirable compressive forces are only influential to a depth of 2,0 mm.

It appears that if the basic design principles are adhered to, the metal's physical and mechanical properties and the residual stress at the bond site have a greater effect on the ultimate fracture strength of a metal ceramic crown than the design of the framework (Marker *et al.*, 1996:567). In their study the compressive strengths of base metal versus noble metal ceramometal restorations were tested with various frame designs. In the light of this, it was safely assumed that the results obtained from the present study could be applicable and therefore of value to the dental industry.

### *2.4.1 Factors influencing bond strength*

According to Yamamoto (1985:147) metal conditioners are surface treatment agents for metal alloys, used to improve the bond and colour of porcelain once applied to the metal alloy. They also assist in preventing interfacial bubbles between the metal and porcelain. These metal conditioners were mainly introduced due to the problem associated with thick base metal oxides that negatively affected the quality of the metal ceramic bond and the aesthetics of porcelain. The Bredent chrome cobalt bonding agent ( Nova Dental, Johannesburg) that was used in this study, is a ceramic based formula intended to improve bonding where the oxide formed on the metal alloy is not desirable for metal ceramic bonding.

Since base metals alloys have a less desirable thick oxide formation than noble metal alloys, this metal conditioner was used to maximize the strength of the base metal alloy test samples.

## 2.5 PROBLEMS RELATED TO METAL CERAMIC FAILURE

Augmenting the aesthetics of porcelain with the strength of metal has solved many problems that other materials were unable to do. However, through the evolution of metal ceramics there have been countless clinical problems and failures, as is evident by the volume of literature and research devoted to improving these problems
(Preston, 1984:9- 22).

According to Preston (1984:9-22) there are numerous problems that have been related directly to base metal ceramic restorations since the patent of a metal ceramic restoration by Weinstein, whereby the metal ceramic unit has become the most extensively used aesthetic restoration in dentistry.

The success of this technique is due to a process of fritting whereby the incorporation of leucite crystals allows for sufficient expansion of the porcelain to allow a coefficient of thermal compatibility between the alloy and porcelain, which permits bonding of these two materials.

Today the metal ceramic restoration is advertised as a perfect product. However, although most problems have been ironed out and it is seen as a successful restoration technique, there are still many problems and areas that are not clearly understood.

Such problems include chipping, crazing, porcelain popping off, marginal distortion, shade problems, and discolouration to name a few. The answers to all these problems may not always be obvious, but with careful analysis these may be reduced if the process of manufacture is better understood. The processing of a metal ceramic restoration places the metal under the most extreme conditions imaginable. It is cast, ground to fit the die and then subjected to at least five firings at high temperatures. The nearer the alloy substructure is fired to its melting range the more likely it is that it will distort during firing; as a result base metal alloys with a higher melting range are more suited to resist distortion than noble metal alloys. However, low fusing porcelains can also be utilized to address this problem (Preston, 1984:9-22).

The greatest confusion according to Preston (1984:9-23), however, surrounds the vast number of alloy types available. This is evident even within the group of base metal alloys. The selection of an alloy should be rational, as it should allow for compatibility with the porcelain of choice, be easy to manipulate, possess desirable physical characteristics and be cost effective. Not merely the alloy alone but also interface reaction with porcelain, melting temperature, yield strength, modulus of elasticity, castability and accuracy are to be considered.

A high modulus of elasticity is particularly important, since low levels will allow the porcelain to distort, and porcelain distorts cataclysmically beyond 0.1% deformation, resulting in what is referred to as a modulus of rupture. The modulus of porcelain is about 16,000,000 p.s.i. and a greater mismatch of metal to porcelain moduli, means that the coefficient of thermal expansion must match well to ensure success. Further it has been found that vacuum pressure induction casting provides the most complete and controllable casting for base metal alloys( Strietzel, Bego article undated). Controllable casting of an alloy also depends on proper mold temperatures being observed. The mold temperatures given by manufacturers are often average temperatures.

The temperature should allow optimum fluidity, but must not overheat the alloy at all as this will cause it to expand more, resulting in a smaller volume of the alloy filling the mold and  a greater degree of final shrinkage of the alloy that is not desirable. This will in turn require a need for greater mold expansions, since expansions of a mold are not totally uniform, and excessively large mold expansions due to excessive alloy shrinkage on cooling is not desirable (Strietzel, Bego article, undated).

The alloy must also be completely biocompatible and must not corrode or allow any toxic leakage, as this will cause health implications, the cause of which may not be easily diagnosed (Strietzel, Bego article, undated).

Although there are many more alloys on the market than porcelains, certain porcelains may be subject to greater discolouration by specific alloys than others, and the degree of oxidation may influence the thermal expansion compatibility of the porcelain. Therefore, although the coefficients are theoretically compatible, it does not mean that there may not be external factors that may create further problems. Trial and error thus sometimes seems to be the only way of confirming success of metal ceramic restorations over a long period of time (Yamamoto, 1985:18-25).

One of the greatest areas of frustration has been the bond interface. Success here relies largely on the correct thickness and type of oxide being produced by the alloy. The success of metal ceramics relies on a good interface reaction between alloy and porcelain. Only a monomolecular oxide layer is needed for optimum bonding, and since base metal alloys produce much larger quantities of oxide, which in turn tend to have an inferior bond with noble metal alloys, an acceptable bond is required to warrant success (Yamamoto, 1985:107-114).

The coefficient of thermal expansion involved in bonding has probably caused the greatest frustration in developing the metal ceramic restoration, and is one of the more difficult areas to study accurately. Due to the properties of porcelain there are so many variables that only guidelines are given and the coefficient of expansion cannot be determined with 100% accuracy (Yamamoto, 1985:162-168).

According to Yamamoto (1985:177-190) coefficient of thermal expansion changes with the following factors that relate to leucite crystal growth:

1. The rate of temperature rise.
2. The final temperature reached and amount of time it is held at maximum temperature.
3. The cooling rate.
4. The number of times it is fired.

The metal should ideally contract a bit more than porcelain on cooling. Due to the metal ceramic bond  the porcelain is placed in compression to maximize its strength.

The coefficient of thermal expansion of porcelain is not predictable on repetitive firing and may increase or decrease within the first five bakes after which, by the seventh bake, it will remain constant. Unfortunately by this time the porcelain has defitrified and discoloured to an unacceptable level (Yamamoto, 1985:177-190).

Porcelain itself has many variables, and porcelains vary greatly from different manufacturers. Metal oxides may be added in order to increase the coefficient of thermal expansion further and make the bonding process possible. This may however weaken the porcelain; but certain metal oxides such as tin oxide may increase the bond strength markedly as well and are obtained by including tin in the alloy.

The success of porcelain also relies heavily on following recommended design and alloy finishing techniques, but the main advantage is obviously that of its ability to achieve the desirable aesthetics. Unfortunately this ability is not always utilized to its full potential, and relies heavily on the artistic and technical ability of the operator (Yamamoto, 1985:220).

Personal observations by the researcher regarding operation techniques in South Africa confirm that locally the same problems are encountered, and have to be dealt with on a day-to-day basis. There is a tendency from some laboratories to continually look out for and try new cheaper products, which often results in a new untested combination of porcelain to base metal alloy that results in numerous teething problems that must first be resolved. Other laboratories are so afraid of upsetting a working balance that has been established by years of trial and error, that they are reluctant to change or try new materials due to the problems that may have to be eliminated sequentially all over again.

There is also a tendency to mass production of metal ceramic restorations where a similar technique utilizing a constant coping thickness is utilized regardless of the available space. This technique results in different thickness of porcelain for different restorations. This often results in certain restorations not having sufficient metal alloy support. Fixing and restoring cracked and chipped porcelain on old base metal ceramic crowns is a frustrating process especially since the type of alloy and porcelain used may not be known as it may have been made in a different laboratory. As a result, there is an understandable resistance to take responsibility for another laboratory's work and some laboratories may insist on rather remaking the restoration, at the patient's expense (Personal communication, Loewenstein, 2000).

## 2.6 SUMMARY

The foregoing literature review has explained the problems related to strength and aesthetic factors of metal ceramic alloys, particularly as related to base metal alloys. These can be summarized as follows:

Base metal alloys are being used extensively, and depending on the alloy may produce as acceptable results as noble metal alloys, while having added advantages of a high modulus of elasticity, thereby allowing their use in longer span bridges.

Some base metal alloys may not be biologically acceptable and should not be used for metal ceramic restorations. Moreover, all base metal alloys do not posses the same characteristics.

Porcelain is a brittle material that in metal ceramics relies on the support of the alloy substructure design and the interface bond to be successful; its failure being a result of crack propagation due to tiny surface flaws that are especially prone to propagate when the material is subjected to tensile stresses.

There is uncertainty as to the thickness of the alloy substructure required to ensure success, although strengthening mechanisms for porcelain and the alloy individually seem to be well founded.

The greatest area of uncertainty still seems to be understanding the mechanism of porcelain to metal alloy bonding, particularly with regard to factors that influence the coefficient of thermal expansion.

Correct techniques and design considerations are also important factors to consider in order to ensure success of metal ceramic restorations. The greatest contributing factor of the metal ceramic restoration is the ability to combine excellent aesthetics with adequate strength. In order to get the desired results that are possible, if correct procedural planning is observed, which implies that the results rely on a high demand of artistic ability of the operator.

# CHAPTER THREE

## 3.0 THE DATA

### 3.1 PRIMARY DATA

The following primary data were obtained:

- Strength values for seven variations in metal alloy thickness measured in Newtons.
- Strength values for seven variations in porcelain thickness measured in Newtons.
- Strength values for the noble metal alloy control measured in Newtons.
- Statistical values obtained from the one-way sample Analysis of variance test.

The above data were evaluated and interrelated in order to establish parameters for base metal ceramic restorations so that recommendations could be made regarding thickness ratios of alloy to porcelain as compared to the evaluation of the noble metal alloy control group.

## 3.2 SECONDARY DATA

The following secondary data were considered as important guidelines to this study:

- That 1,0 mm of porcelain is needed to match a shade, and allow desired aesthetics.
- That the alloy substrate should not allow more than 2,0 mm thickness of unsupported porcelain, as this would weaken the porcelain considerably.
- The recommendation by Yamamoto (1985), who suggested that the base metal alloy not be reduced much below 0,3 mm in order to ensure the success of the restoration.
- The recommendation by Weiss (1983), that the alloy may routinely be reduced to 0,1 mm in order to increase aesthetics while ensuring success, was also followed.

### *3.2.1 CRITERIA GOVERNING THE ADMISSIBILITY OF DATA*

- Only the data and statistical analyses recorded by the Instron 44 were used.
- Only metal ceramic specimens made by the researcher in the laboratory of the Technikon Natal were used.

## 3.3. METHODOLOGY

### *3.3.1. METHODS (General Description)*

The base metal alloy that was used for all three sub-problems, was Wiron 99 (Bego, Germany), which is one of the most popular nickel- chrome base metal alloys used in South Africa, (Personal communication, Somers, 1988).

The gold-palladium noble metal alloy containing a gold content over 75%, Bio Y 81 (Argen, Johannesburg) was used because its composition closely resembles early metal ceramic alloys that are still in use, thereby giving validity to its use as an acceptable noble metal alloy control.

The next step was to establish strength values for base metal alloy for the three sub-problems and the noble metal alloy ceramic control group. A total of 100 base metal alloy specimens were manufactured and a further 12 specimens cast in a high gold content noble metal alloy. Each specimen was marked to allow individual identification. The tensile strengths of the samples were determined using the Instron 44 testing machine, which was calibrated and set by the technical advisor of the Instron sales team.The tensile strengths of the samples were recorded in Newtons.

For Sub-problem One, strength values of base metal ceramic test samples were measured, where the metal thickness was varied while maintaining a constant porcelain thickness.

For Sub-problem Two, strength values of base metal ceramic test samples were measured, where the porcelain thickness was varied while maintaining a constant metal thickness.

For Sub-problem Three, strength values where the thickness of both porcelain and base metal alloy ratios was varied, were measured. The specific approach in establishing a control group was to measure strength values of noble metal ceramic test samples of minimum permissible thickness in porcelain and metal alloy, as a control. The porcelain to alloy thickness ratios were constant, with a porcelain thickness of 1,0 mm and noble metal alloy thickness of 0,3 mm.

*SAMPLE PREPARATION*

### *3.3.2 SAMPLE GROUPS (indicating group size)*

Since the main thrust of this investigation was to explore the relationship between the alloy and porcelain thickness, the resulting elements (Table 3.1) formed the basis for the design criteria. Table 3.1 indicates the alloy to porcelain thickness ratios of samples, and the number of samples in each sample group.

TABLE 3.1 Alloy to Porcelain Thickness Ratios of Samples

| | Alloy thickness | Number of samples | Alloy thickness | Porcelain thickness | Combined thickness |
|---|---|---|---|---|---|
| SP I | Varying base metal alloy thickness | 10 | 0,1 mm | 1,0 mm | 1,1 mm |
| | | 10 | 0,2 mm | 1,0 mm | 1,2 mm |
| | | 10 | 0,3 mm | 1,0 mm | 1,3 mm |
| | | 10 | 0,4 mm | 1,0 mm | 1,4 mm |
| SP II | Varying porcelain thickness | 10 | 0,1 mm | 0,7 mm | 0,8 mm |
| | | 10 | 0,1 mm | 1,3 mm | 1,4 mm |
| | | 10 | 0,1 mm | 1,6 mm | 1,7 mm |
| SP III | Varying porcelain and base metal alloy thickness | 10 | 0,2 mm | 1,6 mm | 1,8 mm |
| | | 10 | 0,3 mm | 1,3 mm | 1,6 mm |
| | | 10 | 0,4 mm | 1,6 mm | 2,0 mm |
| IV | Noble metal alloy and porcelain thickness (control) | 12 | 0,3 mm | 1,0 mm | 1,3 mm |

Ten repetitions of each sample group, using the same alloy/porcelain thickness, were performed. The total of all samples, including the noble metal ceramic group, was 112 samples.

The twelve control samples were manufactured with an alloy thickness of 0,3 mm and porcelain thickness of 1,0 mm using Bio Y 81 high gold content noble metal alloy and Creation porcelain.

The minimum base metal alloy thickness was 0,1 mm, since processing procedures to cast thinner sections are not advisable (Weiss, 1983: 232). The maximum thickness used for the base metal alloy was 0,4 mm, which was 0,1 mm thicker than the control, giving more than sufficient strength. If the metal thickness increases, available space for porcelain decreases, creating an aesthetic problem (Kersten, 1988: 383).

The minimum porcelain thickness was 0,7 mm in order to get a lower value than the desired 1,0 mm thickness of porcelain that is needed to match a shade (Kersten, 1988: 383).

The maximum thickness of porcelain was 1,6 mm, because if the porcelain thickness should increase beyond 2,0 mm, its strength would decrease remarkably (Yamamoto, 1985:189-190). Mack *et al.*(1997), also stated that porcelain thickness in preparations should not exceed 2,0 mm. As a result the maximum thickness of porcelain combined to the maximum thickness of base metal alloy in this study did not exceed 2,0 mm, as can be seen in

Table 3.1.

## 3.4 MANUFACTURING PROCEDURE

### *3.4.1 WAX PATTERN PRODUCTION*

In order to establish the strength values of various ratios of alloy to porcelain thickness, 10 samples of 10 sample groups +12 control samples = 112 specimens in total were manufactured. The specimens were manufactured using the lost wax technique.

All the wax patterns were punched out of 0,4 mm thick Dentaurum pattern wax ( Dentaurum, Ag Germany) using a finger punch ( Figure 3.1). Specimens were carefully removed from the finger punch by means of a plunger and placed on a flat surface to prevent distortion. These patterns were 5,8 mm wide and 15,0 mm long.

The finger punch was manufactured out of brass to avoid corrosion of the instrument, which in turn might have affected casting of the samples if the wax were contaminated. The punch consisted of a rectangular cutting box and a pattern plunger. The outside edge of the cutting box was machined with a slight taper toward the cutting edge to allow the wax pattern to be cut out. The pattern plunger then allowed the wax specimens to be removed without distorting them. The cutting of the pattern was achieved by placing a 0,4 mm thick wax sheet on a flat surface and depressing the cutting cylinder by hand until the pattern was cut. Then the plunger was inserted from the other open end to carefully remove the wax pattern.

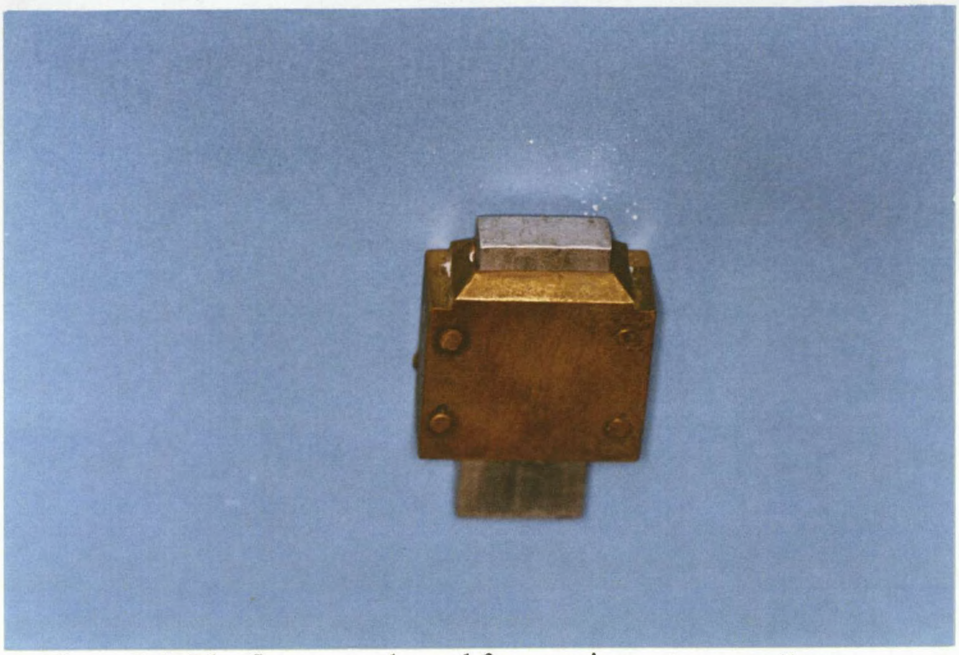

Figure 3.1 The finger punch used for pressing out wax patterns

### *3.4.2 WAX PATTERN*

Bego 3.5 mm round sprue wax ( Bego, West Germany) was used. The length of sprues was 6mm as recommended for casting directly to the base of the sprue former (Anusavice, 1996:497-498). Two sprues were used for each sample. Sprues were thinned down and tapered at the connection points, and 6-8 sprued patterns were attached to the base with green Kerr inlay wax. Specimens were aligned parallel to each other for easy cutting of sprues and recovery of the samples.

### *3.4.3 CASTING WAX SPECIMENS*

The quantity of gold alloy required for 12 samples was calculated as follows:

A x B = C

- A = weight of sprue former with attached patterns minus the weight of the sprue former = 1,0 g
- B = specific gravity of gold alloy = 18,6
- C = weight in grams of alloy required to cast the pattern

The sprue former was weighed before wax patterns and sprues were attached. Then the patterns and sprue former were weighed and the weight of the sprue former was deducted to give the weight of the wax patterns and sprues only. Having calculated the weight of metal required, the amount of gold alloy required was weighed and the samples were cast. Since base metal is inexpensive and a reservoir is required to reduce porosity, the samples for base metal were not weighed in wax, but 3 ingots proved ideal for 8 samples. Each ingot weighed 6 g = 3x6 = 18 g.

### *3.4.4 INVESTING OF WAX PATTERNS*

In this study, 6-8 patterns were invested at a time in the conventional way using 100% expansion liquid. A single Kera-Vlies muffle ring liner 1.0450 mm (Dentaurum, Germany) was placed in the ring, to aid in the deflasking process. Wax patterns were sprayed with Waxit spray (Degussa AG, Frankfurt).

The contents of two packets (60g) each of Bellavest T (Bego, West Germany) was placed in a Multivac 4 mixing bowl (Degussa, AG Frankfurt) and mixed with 28 ml of water. The Bellavest T and liquid were spatulated for 60 seconds. The investment was then poured into the muffle and allowed to set for an hour before being placed in a burn out oven.

### *3.4.5 BURN OUT CYCLE*

All burn out cycles were conducted in a KWO/EWL type 5645 (Germany) burn out furnace. The muffle went through the following burn out cycle before the base metal alloy was cast:

1. Room temperature to 250°C (60min).
2. To 650°C (50min)
3. To 960°C (60min)

For gold alloy stage 3 only went up to 910°C for 60 minutes. A maximum of 2 muffles were placed in the burn out oven at one time and the burn out cycle of the gold alloy samples was done separately.

### *3.4.6 CASTING OF SPECIMENS (CENTRIFUGAL)*

On reaching the desired temperature the samples were cast as follows:

The crucible was placed in the centrifugal casting machine, which was wound up four times. The gas/oxygen flame was set medium-high for metal alloy and medium for the gold alloy samples.

The crucible was first heated by flame until it was heat soaked, then the desired metal alloy was placed into the crucible and heated. Just before melting temperature of the alloy, the muffle was placed in position as the metal alloy just melted right through (for base metal as it slumped, and for gold alloy as it formed a ball and started spinning). The sample was then cast by centrifugal force.

### *3.4.7 RECOVERY OF CASTINGS*

All investment rings were allowed to cool to room temperature. The investment rings was lightly tapped until the investment broke away and the samples were removed one by one by cutting through the sprues with a cutting disc. All samples were then sandblasted with 110-micron aluminium oxide.

### *3.4.8 TRIMMING AND GRINDING THE SURFACE OF SAMPLES*

The samples were then trimmed to size with cutting discs by removing the excess of the sprues. Then a trimming wheel was used to thin the samples to size. The blue mounted stones (Bego, AG Germany) were used for the rough trimming after which a cross cut carbide bur (Edenta, AG Switzerland) was used for the final surface, since carbide burs do not leave any residue and produce a desirable texture (Yamamoto, 1985). A standard thickness guage was used to ensure that uniform thickness was achieved for each sample.

Holding the samples in artery forceps the samples were then sandblasted again, without touching the surface with any contaminants. Metal samples were sandblasted with 110 micron aluminium oxide, as recommended by Bego, (W. Germany).

The gold alloy samples were sandblasted with 50 micron aluminium oxide as recommended for noble metal alloys since it is softer. The samples were washed in distilled water to remove any sand and dirt.

### *3.4.9 PORCELAIN APPLICATION*

All firing cycles were performed using a Vita 300 vacumat. The base metal alloys were given an oxidation firing with a Bredent metal conditioner ( Nova dental, Johannesburg) applied as a wash. This was to maximize the bond due to the nature of base metal oxides.

Base metal oxides are slightly inferior to the gold alloy oxides for achieving bonding strength. The base metal alloys were oxidized with an opaque wash according to recommendations( Marx, 1997). Oxidation was performed without vacuum or a holding temperature, as follows:

1. Drying form: 600°C for 2 minutes
2. Temp climb: 80°C per minute
3. Final temp: 980°

After oxide firing, the specimens were allowed to cool to room temperature. Excess oxide was washed off using a toothbrush and distilled water, and an opaque layer was placed over the washed opaque conditioner, using Creations opaque liquid for maximum condensation of the opaque. Opaque was applied with a brush while the sample was held between tweezers.

The samples were vibrated to condense the opaque and get an even layer opaque of 0,2 mm after firing. The 0,2 mm thickness was achieved by consistently controlling the thickness of opaque applied to just block out the greyness of the base metal alloy. The 0,2 mm thickness of opaque was confirmed by using the thickness guage and subtracting the alloy thickness measured

The opaque was fired as follows:

1. Drying form: 600°C for 3 minutes
2. Temp climb: 80°C per minute
3. Final temp: 960°C for base metal alloys and 950°C for gold alloys
4. Holding time: 1.00 minute
5. Vacuum: Yes

All samples were fired in sample batches in order to allow identification and to prevent mixing them up. They were stored in containers marked clearly with the alloy thickness.

### *3.4.10 FIRING DENTINE*

Layering was performed using a layering depth gauge (a detailed description of the depth gauge follows at the end of this section). This allowed exactly the same dimensions of porcelain to be applied regarding length and breadth of sample, resulting in consistent amounts of porcelain for each sample group. The opaque specimen was placed in the depth gauge, after zeroing the digital display of the depth gauge when the plunger was level with the outer surface. As the plunger descended, the depth was indicated on the LCD display.

The depth gauge ( Fig 3.2) was used to get more consistent amounts of porcelain on the metal alloy surface to ensure that firing shrinkage and porcelain thickness for each sample group were consistent.

The technique used allowed the correct amount of porcelain to be built up so that after firing the samples had marginally thicker porcelain depths than was planned for after the first bake only. This was necessary because the center of the samples seemed to shrink slightly more and the edges were then trimmed slightly to create the constant thickness of porcelain required. The depth gauge chosen utilized a modified digital vernier with an LCD display and accuracy of approximately 0,03mm ( Figure 3.2).

The modified digital vernier was linked to the manufactured portion of the depth gauge which consisted of a rectangular shaped box conforming to the sample size and a piston that matched the rectangular shape perfectly. The rectangular box and piston were made of brass to prevent corrosion that might interfere with porcelain properties on firing. The samples fitted perfectly into the shape of the box diameter, but were slightly shorter than the length, which did not pose a problem during the build-up technique, and very consistent results were obtained regarding porcelain depth on application.

The depth gauge had a locking mechanism which allowed it to be locked into position during the application of porcelain to allow repeated results and measurements. A fine adjusting screw was incorporated to allow fine adjustments and reduce the time taken in reaching exact measurements.

By subtracting the thickness of the alloy, porcelain depth could be calculated and the desired thickness of alloy and porcelain combination was obtained. These measurements were reinforced by using a thickness gauge, used commercially to measure thickness of alloy and porcelain.

The samples were manufactured in the same way as restorations in a dental laboratory are made. Dentine porcelain powder mixed with distilled water was then compacted into the space provided and onto the opaque layer of the sample.

A paper tissue was used to dry out the porcelain and remove excess porcelain above the outer surface of the gauge (to level it off). The samples were removed and fired in batches of ten, corresponding to each sample group.

The dentine firing cycle was as follows:

1. Holding time: 600°C for 3 minutes
2. Raise of temp: 55°C per minute
3. Final temp: 920°C
4. Holding time: 1.00 minute
5. Vacuum: Yes

After firing, each sample was ground with a fine ceramic stone burr to the desired thickness of porcelain required. This was achieved using a depth gauge still calibrated exactly as for the metal alloy thickness recorded. The alloy thickness was deducted from the total sum thickness with porcelain to allow grinding the porcelain down to the exact desired thickness for each sample group. These values are recorded in the table of results in Chapter 4. The samples were then self glazed without glazing liquid, since this produces the most desirable finish for strength (Yamamoto, 1985:422-423). Each batch of 10 was glazed together.

The glaze cycle without vacuum was as follows:

1. Holding time: 600°C for 2 minutes
2. Raise of temp: 55°C per minute
3. Final temp: 930°C
4. Holding time: none
5. Vacuum: none

The depth gauge utilized was an adaptation of a similar instrument used by Somers (1998), the difference being that the samples in this study were rectangular in shape, unlike those of Somers which were round samples. However the principle remained the same.

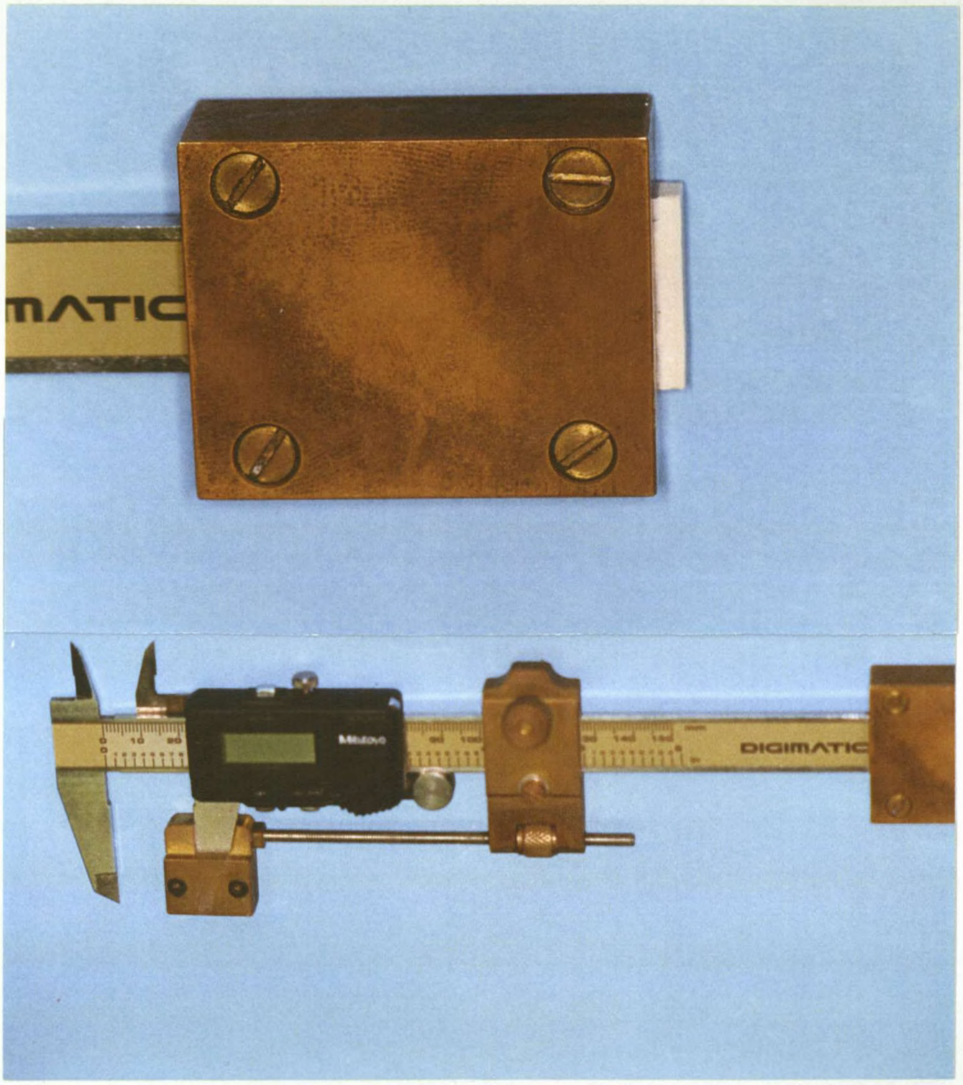


Figure 3.2 The depth guage used for the porcelain layering technique

### *3.4.11 NUMBERING AND IDENTIFICATION OF SPECIMENS*

The specimens were numbered so that they could be identified individually ( Table 3.2), and the results of tensile strength tests could be recorded for each test sample.

Table 3.2 Sample Groups and Numbers

| Control group-X | Group A | Group B | Group C | Group D |
| --- | --- | --- | --- | --- |
| Metal- 0,3 mm | Metal- 0,1 mm | Metal-0,2 mm | Metal- 0,3 mm | Metal- 0,4 mm |
| Porcelain-1,0 mm | Porcelain-1,0 mm | Porcelain-1,0 mm | Porcelain-1,0 mm | Porcelain-1,0 mm |
| Noble metal alloy | Base metal Alloy | Base metal alloy | Bease meatal alloy | Base metal alloy |
| Numbered 1-12 | Numbered 1-10 | Numbered 1-10 | Numbered 1-10 | Numbered 1-10 |
| E | F | G | H | I |
| Metal-0,1 mm | Metal-0,1 mm | Metal-0,1 mm | Metal-0,2 mm | Metal-0,3 mm |
| Porcelain-0,7 mm | Porcelain-1,3 mm | Porcelain-1,6 mm | Porcelain-1,6 mm | Porcelain-1,3 mm |
| Base metal alloy | Base metal alloy | Base metal alloy | Base metal alloy | Base metal alloy |
| Numbered 1-10 | numbered 1-10 | numbered 1-10 | Numbered 1-10 | Numbered 1-10 |
| Group-J | | | | |
| Metal-0,4 mm | | | | |
| Porcelain-1,6 mm | | | | |
| Base metal alloy | | | | |
| Numbered 1-10 | | | | |

## 3.5 FACTORS INVOLVED IN SAMPLE TESTING

According to Binns (1983) the following factors must be considered during sample testing of porcelain specimens. These factors were noted and incorporated into the methodology for testing the metal ceramic samples.

### *3.5.1. CERAMIC MATERIALS FAILURE*

Ceramic materials fail due to low tensile strengths; therefore the tensile strength of porcelain must be measured. This strength is maximized in the lower curved surface of the loaded beam. Hence this study used the 3-point bending test whereby the point of the loaded beam contacted the metal alloy surface, thereby exposing the ceramic material to maximum tensile forces.

In order to measure the tensile strength and not compressive strengths of porcelain, it was necessary to place the samples with the porcelain surface facing downward. The sample rested on two flat metal surfaces on either side with a third point, measuring the fracture resistance in Newtons, being lowered from above onto the middle of the alloy surface of the sample. As this third point started bending the sample in the direction of the porcelain surface, this surface was bent outward placing the porcelain in an immediate state of tension.

### *3.5.2. MODULUS OF RUPTURE*

Modulus of rupture values for porcelain tend to range between 28-70 Mpa. However, comparing the results with those of different studies was very difficult due to variations in specimen size, preparation loading rate and span to depth ratios.

All ceramic materials fracture at the same critical strain value of approximately 0.1% (Jones, 1983:83-142). This means that if the material is flexed even slightly it will crack. With regard tothis study it was important to accurately measure the modulus of rupture. In order to do this the Instron 44 tensile testing machine was used, as it could be set to be stopped as soon as the initial porcelain failure occurred. The samples were as a result not bent at all, showing only a hairline crack produced as a result of just reaching the modulus of rupture value.

### *3.5.3. CROSS BREAKING*

Consistent cross breaking values are increased if the span to depth ratio is greater than ten to one with a 5:1 span to depth being on the border line (Jones, 1983:83-142). Therefore, the span to depth ratios of samples were such as not to exceed these parameters. The samples were 5.8mm wide and 15.0mm long, with the thickest sample being 2,0 mm thick. Clearly the span to depth ratio was much greater than 5:1 and cross breaking results adhered to this design principle for accurate and consistent results.

### *3.5.4. FREE ROTATION*

Test samples should be free to rotate on loaded points, to prevent increased bond strength values from preventing consistent tensile strength measurements (Jones, 1983:83-142). By allowing the samples to rest freely on either end of the smooth glazed surface, they could freely rotate, so that the porcelain's fracture strength alone, and no other external force component, was measured. Since the porcelain samples were glazed to a smooth finish they could freely rotate with minimal friction, to allow consistent results.

## 3.6. ADMINISTRATION

1. The mean tensile strength of samples, when tensile fracture occurred, was measured in Newtons, using an Instron 44 testing machine operating on 95% confidence level. These base metal ceramic strengths for each sample were then compared to the strength values of the noble metal ceramic test samples for minimum acceptable strength values. This indicates where base metal ceramic thickness has been reduced in porcelain, metal alloy or both to an unacceptable extent.

The Instron 44 tensile testing machine was set to operate at a cross head speed speed of 0,5 mm per minute. The samples were placed with the porcelain surface facing downward resting between two smooth metal plates 10mm apart, to allow free rotation during testing. As soon as the porcelain cracked at the modulus of rupture, a reading of force resisted in Newtons was recorded for each sample.
Statistical analyses of the data of sample groups was done to assist in establishing critical strength values.

Strength values of base metal ceramic samples above the acceptable values as indicated by the noble metal ceramic control, resulted in recommendations for strength and aesthetic characteristics to be maximized in restorations for varying degrees of available space for metal and porcelain.

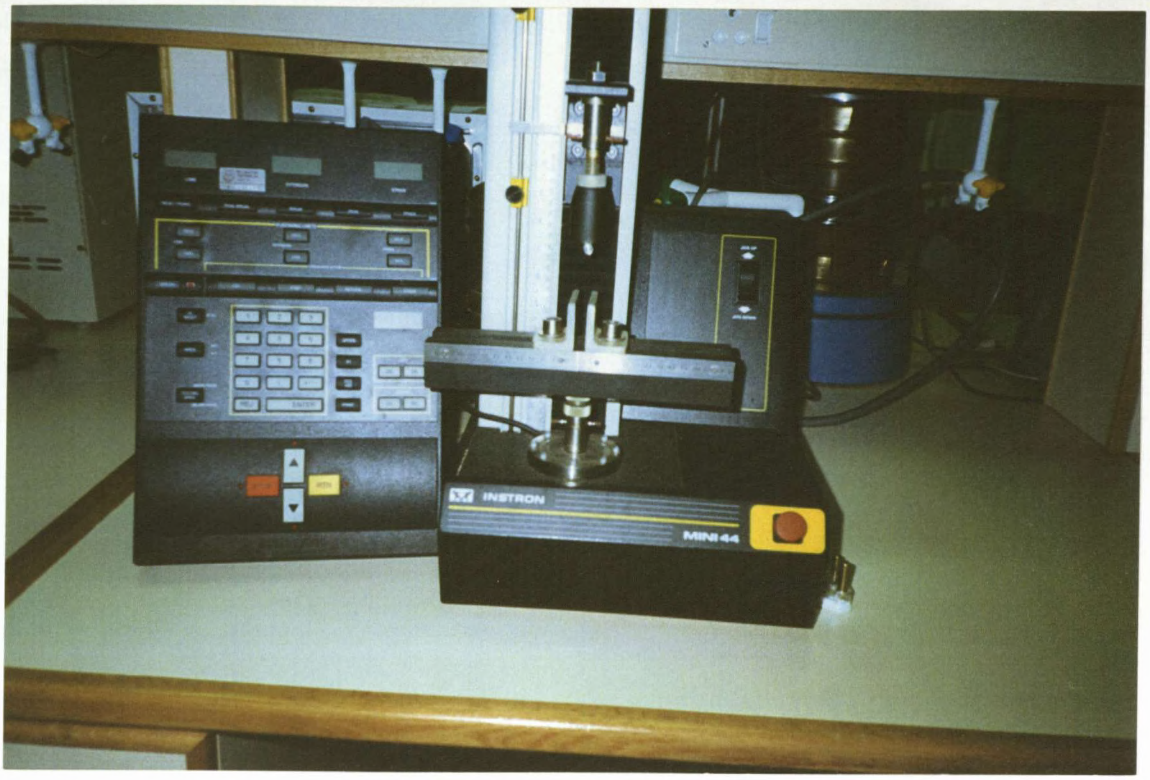


Figure 3.3 The Instron 44 Testing Machine, Instron Corporation, U.S.A.

### 3.7 STATISTICAL METHOD

The statistical method utilized was the univariate Analysis of Variance, or one- way sample analysis of variance (Personal communication, Worku, 1998). The reason for using the one-way ANOVA test was because of the important role that the control sample group had in setting a standard of clinically acceptable strength values against which each sample group had to be compared and evaluated.

Those sample groups that had samples with strength values below the lowest value of the control sample group therefore did not meet the required strength values for clinical acceptability .

In order to maximize strength and aesthetic requirements, the specimens in each sample group that met the strength requirements of the clinically acceptable control group were compared individually with one another in order to allow for an analysis of each sample group's strength and aesthetic characteristics. The one-way ANOVA was therefore an important statistical method that allowed comparisons in order to make recommendations for metal ceramic design that would maximize strength and aesthetic requirements for restorations.

According to Leedy (1985:195-196) coefficient of variation (CV) indicates the relative magnitude of the Standard Deviation (SD) as compared with the mean of the distribution of measurements as a percentage. Thus the formula is: CV= SD x 100/Mean. The coefficient of variation is useful to compare variability of two data sets relative to the general level of values (and thus relative to the mean in each set).

The statistical numbering system used to identify sample groups is given in Table 3.3.

Table 3.3 : Statistical Numbering System

| Sample Groups | Group Number | Number of Samples |
|---|---|---|
| X-Control Group | 1 | 12 |
| A-Base metal alloy | 2 | 10 |
| B-Base metal alloy | 3 | 10 |
| C-Base metal alloy | 4 | 10 |
| D-Base metal alloy | 5 | 10 |
| E-Base metal alloy | 6 | 10 |
| F-Base metal alloy | 7 | 10 |
| G-Base metal alloy | 8 | 10 |
| H-Base metal alloy | 9 | 10 |
| I-Base metal alloy | 10 | 10 |
| J-Base metal alloy | 11 | 10 |

## 3.8 SPECIFIC TREATMENT OF EACH SUB-PROBLEM

### SUB-PROBLEM ONE

Sub-problem One was to investigate the performance of base metal alloy restorations with reference to variations in thickness in the alloy in order to establish strength characteristics of metal alloys in restorations. Strength measurements of test samples where the metal alloy thickness was varied were measured in Newtons.

Figure 4.1 was drawn up to demonstrate the relationship between metal alloy thickness and strength of the metal alloy, when bonded to porcelain. These values were compared to the noble metal alloy control group to clearly indicate the performance of the metal alloy variance in thickness in order to establish strength characteristics of metal alloys in restorations. These results are shown in Table 4.1.

### SUB-PROBLEM TWO

Sub-problem Two was to investigate the performance of base metal ceramic restorations with reference to variations of thickness in porcelain in terms of strength and aesthetic characteristics in order to establish strength and aesthetic characteristics of porcelain in restorations. Strength measurements of test samples where porcelain thickness was varied were measured in Newtons. Relationships between strength measurements and sample thickness are illustrated in Figure 4.2 to show the relationship between porcelain thickness and strength of porcelain when bonded to a metal alloy. These values were compared to those of the noble metal alloy group to indicate the performance of porcelain variance in thickness, in order to establish strength characteristics of porcelain in restorations. These results are shown in Figure 4.2 and Table 4.2.

## SUB-PROBLEM THREE

Sub-problem Three was to integrate strength characteristics of the metal alloy with the strength and aesthetic characteristics of porcelain in order to establish criteria to maximize strength and aesthetic characteristics in restorations. The results of Sub-problem One and Two were integrated, and compared to those of the noble metal control in order to maximize strength and aesthetic characteristics in restorations. These comparisons are discussed in Chapter 5.

The relationships between porcelain thickness and strength and metal alloy thickness and strength were integrated to establish the maximum strength values that would allow optimum aesthetics for various permissible space measurements.

# CHAPTER FOUR

## *RESULTS*

## 4.1 DATA RELATED TO SUB-PROBLEMS

### *4.1.1 Sub-problem One*

The results of Sub-problem One indicated the change in strength values of the metal ceramic samples when only the base metal alloy thickness was increased or decreased. These values as compared to those of the noble metal alloy control were used in order to establish strength characteristics of base metal alloys regarding the following:

1. The minimum thickness that the base metal alloy could safely be reduced to and still meet the minimum strength values set by the noble metal alloy control group.
2. The influence that the variations of base metal alloy thickness had on maximizing the strength of metal ceramic restorations as compared to the noble metal alloy control group.

By using these results it was possible to establish the influence that variations of base metal alloy thickness alone had on the strength of metal ceramic restorations.

Table 4.1 Tensile Strengths ( in Newtons) of Sample Groups when the Metal Alloy Thickness was Varied

| | X-Control | | A | | B | | C | | D | |
|---|---|---|---|---|---|---|---|---|---|---|
| | M= 0,3 mm | | M= 0,1 mm | | M=0,2 mm | | M= 0,3 mm | | M= 0,4 mm | |
| | P= 1,0 mm | | P= 1,0 mm | | P= 1,0 mm | | P= 1,0 mm | | P= 1,0 mm | |
| | 1 | 28,09 | 1 | 27,81 | 1 | 34,91 | 1 | 32.21 | 1 | 45,53 |
| | 2 | 37,46 | 2 | 38,54 | 2 | 42,75 | 2 | 43,60 | 2 | 47,73 |
| | 3 | 40,67 | 3 | 39,72 | 3 | 39,29 | 3 | 37,19 | 3 | 43,70 |
| | 4 | 33,50 | 4 | 37,40 | 4 | 39,46 | 4 | 38,85 | 4 | 47,46 |
| | 5 | 35,58 | 5 | 34,09 | 5 | 34,15 | 5 | 36,66 | 5 | 46,20 |
| | 6 | 34,68 | 6 | 32,82 | 6 | 31,56 | 6 | 40,27 | 6 | 44,51 |
| | 7 | 30,97 | 7 | 28,21 | 7 | 28,46 | 7 | 41,57 | 7 | 46,07 |
| | 8 | 34,78 | 8 | 26,75 | 8 | 30,59 | 8 | 44,72 | 8 | 45,15 |
| | 9 | 33,56 | 9 | 35,18 | 9 | 37,45 | 9 | 32,47 | 9 | 47,41 |
| | 10 | 40,16 | 10 | 31,80 | 10 | 33,10 | 10 | 41,03 | 10 | 43,99 |
| | 11 | 37,02 | | | | | | | | |
| | 12 | 41,66 | | | | | | | | |
| highest | 41,66 | | 39,72 | | 42,75 | | 44,72 | | 47,73 | |
| lowest | 28,09 | | 26,75 | | 28,46 | | 32,21 | | 43,70 | |
| mean | 35,67 | | 33,32 | | 35,17 | | 38,86 | | 45,77 | |
| Standard Deviation (SD) | 4,01 | | 4,61 | | 4,50 | | 4,26 | | 1,46 | |
| Coefficient of Variance (CV) | 11,24% | | 13,84% | | 12,79% | | 10,96% | | 3,19% | |

Figure 4.1 is a Histogram bar representation of the strength values of samples when the base metal alloy thickness was varied. The strengthsof all 10 samples in each sample group are shown. The results were compared with those of the control group (Table 4.1).The relevant mean strengths, SD and CV were all calculated. The control group (0,3 mm alloy thickness and 1,0 mm porcelain thickness) complied with clinically accepted standards and was used as a very important guide, since it established the clinically acceptable strength value.

Figure 4.1 shows the strength values in Newtons when the base metal alloy thickness was varied while the porcelain thickness was constant at 1,0 mm.

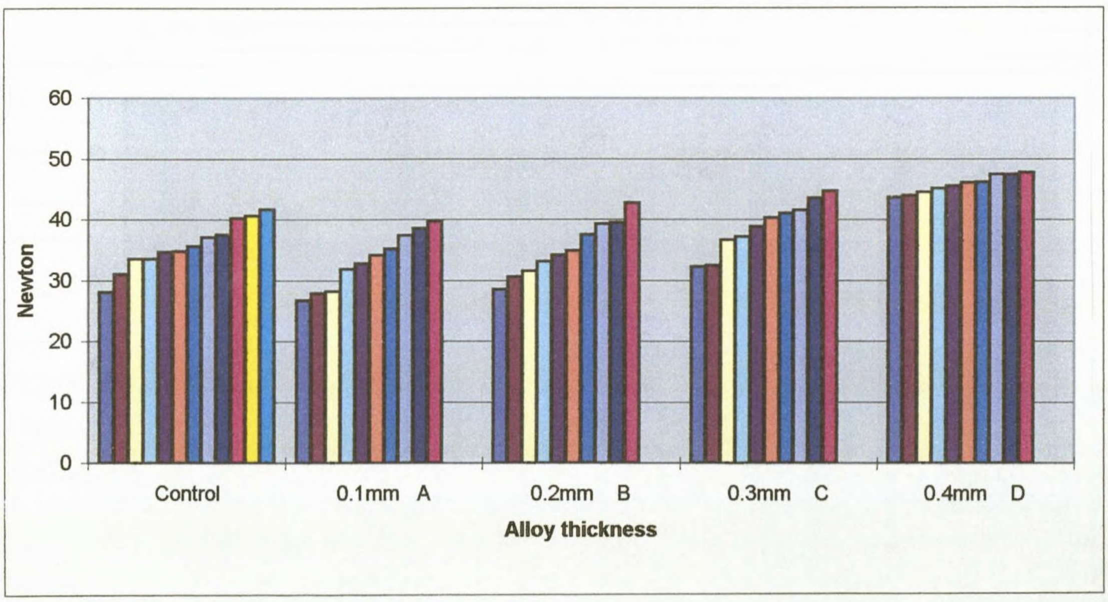


**Figure 4.1 Strength values after variation of base metal in the 40 samples of Group A, B, C and D.**

The effect of the 11 groups was highly significant (P < 0,05) and the confidence level 95%. For sub-problem one the control group showed a mean strength of 35,67 Newtons while the lowest value obtained was 28,09 Newtons and the highest value 41,60 Newtons. Due to the 95% confidence level the lowest value was used for this study. The reason for using the lowest value of the control group was that this was the critical value that would indicate the possibility of clinical fracture. All the base metal alloy samples with lower strength values than 28.09 Newtons did not have acceptable strength values. Table 4.1 shows that the lowest value of each sample group was always slightly closer to that of the control group Than the mean or highest value of each Group. Should the mean or highest values have been used a similar pattern would be observed resulting in the same conclusion and recommendations, but the lowest values indicating possible failure would not have been dealt with adequately.

In the experimental design the metal alloy thickness was increased at regular intervals of 0,1 mm, from 0,1 to 0,4 mm. The 0,4 mm base metal alloy samples, being the thickest, provided more than an adequate increase in strength as all strengths were above 40.00 Newtons. This indicated the importance of maximizing the base metal alloy thickness in providing strength for porcelain support. This is essential when constructing long span bridges, since any flexure of the bridge must be minimized.

Distortion of the alloy substructure may create problems during the manufacturing process of metal ceramic restorations since it may increase the stresses in the porcelain or weaken the porcelain support of the metal ceramic restoration (Yamamoto, 1985:203-220).

The 0,2 to 0,4 mm samples did not distort severely due to working and firing procedures utilized with the base metal alloy. The 0,2 mm and 0,3 mm alloy samples also showed strength values above the control group's lowest value of 28.09 Newtons with the 0,2 mm base metal alloy's lowest value being 28.48 Newtons and the 0,3 mm samples having a lowest value of 32.21 Newtons. Figure 4.1 therefore illustrates that clinically acceptable strength values had been achieved with sample groups B, C, and D, since there are no values below that of the lowest value of the control group. It is thus Assumed (p5) that groups B,C and D would not perform any worse in practice than the clinically accepted
control group.

Two of the 0,1 mm samples in Group A had a low strength values ( 26.75 and 27.81Newtons), than the 28,09 Newton minimum strength requirement established by the noble metal alloy control group. The 0,1 mm samples were also the only samples that distorted, due to distortion that occurred during working and firing procedures. Such distortion of the thin metal alloy sections would therefore require more skill from the operator to obtain an optimum fit, especially in thin unsupported sections of some marginal designs. As a result these samples did not meet the clinically acceptable standard.

The results in Table 4.1 show that increasing the metal alloy thickness increased the strengths of the metal ceramic samples markedly. Maximizing the alloy thickness as far as possible is an important requirement. However, this is not always practically possible due to space requirements. Hence if the porcelain thickness is at the minimum permissible 1,0 mm thickness to match a shade, the alloy should not be reduced to below 0,2 mm. This does however allow a reduction of 0,1 mm from the thickness requirement set for clinical acceptability by the noble metal alloy control group of 0,3 mm, which results in a 33.33% permissible reduction.

Figure 4.1 shows that there was no linear relationship regarding strength values, even though the metal alloy thickness was increased linearly and the porcelain thickness remained constant. This is apparent because although the metal alloy thickness variations were linear from one group to the next while the porcelain thickness was constant, the strength values difference between successive groups differed markedly, increasing unproportionally as the metal thickness was increased.

The coefficient of variation as shown in Table 4.1 was relatively comparable, indicating that the manufacturing process of the samples was good.

The statistical method employed was the one- way sample Analysis of Variance. This allowed the samples to be compared to the clinically acceptable strength values that were set by the noble metal alloy control group to establish clinical acceptability of sample groups.

As the metal alloy thickness was successively increased by 0,1 mm between sample groups (Table 4.1), there was a marked increase in the strength of the samples, indicating that a sufficient increase in the base metal alloy thickness is a critically important design principle to utilize in order to gain sufficient strength for metal ceramic restorations.

### *4.1.2 Sub-problem Two*

The results of Sub-problem Two indicate the change in strength values of the metal ceramic samples when only porcelain thickness was increased or decreased. These values as compared to those of the noble metal alloy control groups were used in order to establish characteristics of variations of porcelain thickness regarding the following:

1. The minimum thickness that the porcelain could safely be reduced to and still meet the minimum strength values set by the noble metal alloy control group when base metal alloy was kept at minimal thickness.
2. The influence that the porcelain thickness had on maximizing the strength of metal ceramic samples as compared to the noble metal alloy control group.

Table 4.1 Tensile strengths (in Newtons) of Sample Groups when the Porcelain Thickness was Varied.

| | X-control | E | A | F | G |
|---|---|---|---|---|---|
| | M= 0,3 mm | M=0,1 mm | M= 0,1 mm | M=0,1 mm | M=0,1 mm |
| | P= 1,0 mm | P=0,7 mm | P= 1,0 mm | P=1,3 mm | P=1,6 mm |
| | 1 28,09 | 1 22,05 | 1 27,81 | 1 51,97 | 1 63,79 |
| | 2 37,46 | 2 18,79 | 2 38,54 | 2 45,69 | 2 59,45 |
| | 3 40,67 | 3 17,69 | 3 39,72 | 3 49,07 | 3 57,58 |
| | 4 33,50 | 4 19,32 | 4 37,40 | 4 39,37 | 4 70,58 |
| | 5 35,58 | 5 21,66 | 5 34,09 | 5 45,03 | 5 55,19 |
| | 6 34,68 | 6 18,04 | 6 32,82 | 6 32,91 | 6 51,79 |
| | 7 30,97 | 7 15,01 | 7 28,21 | 7 41,34 | 7 71,33 |
| | 8 34,78 | 8 16,55 | 8 26,75 | 8 37,68 | 8 59,46 |
| | 9 33,56 | 9 10,44 | 9 35,18 | 9 37,70 | 9 51,84 |
| | 10 40,16 | 10 15,45 | 10 31,80 | 10 28,13 | 10 53,53 |
| | 11 37,02 | | | | |
| | 12 41,66 | | | | |
| highest | 41,60 | 22,05 | 39,72 | 51,97 | 71,33 |
| lowest | 28,09 | 10,44 | 26,75 | 28,13 | 51,79 |
| mean | 35,69 | 17,50 | 33,32 | 40,89 | 59,45 |
| Standard Deviation (SD) | 4,01 | 3,41 | 4,61 | 7,30 | 7,13 |
| Coefficient of Variance (CV) | 11,24 % | 19,49 % | 13,86 % | 17,85 % | 11,99 % |

Figure 4.2 is a graphical representation of the strength values of samples when the porcelain thickness was varied. The strengths of all 10 samples in each sample group are shown. The results from each sample were compared with those of the control group (Table 4.2). The relevant mean strengths ,SD and CV were all calculated. The control group (0,3 mm alloy thickness and 1,0 mm porcelain thickness) complied with clinically accepted standards, established by over 35 years of use and was used as a very important guide since it established the clinically acceptable strength value. According to Yamamoto(1985), the 0,3 mm noble metal alloy thickness provides a 93% level of confidence that sufficient strength will be realised to ensure clinical sucess.

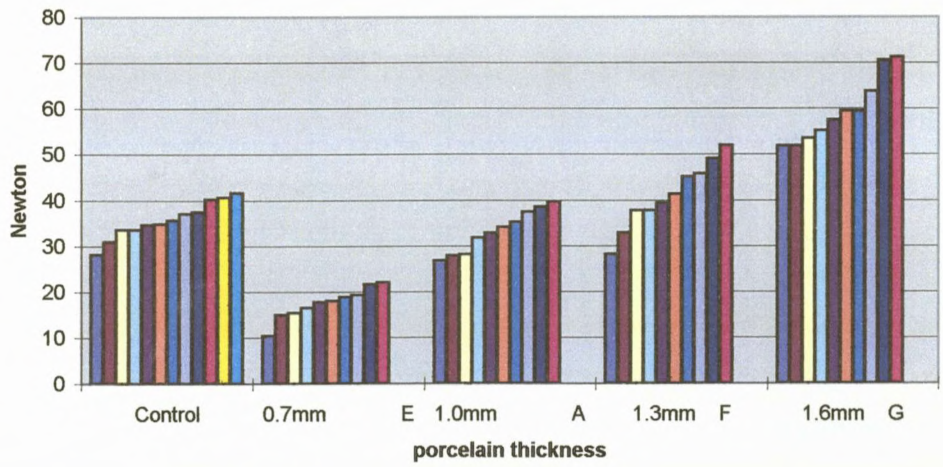


**Figure 4.2 Strength values after variation of porcelain thickness in the 40 samples of Group E, A, F and G.**

For Sub-problem Two the control group showed a mean strength of 35,67 Newtons while the lowest value obtained was 28,09 Newtons and the highest value 41,60 Newtons. For this study the lowest value was used. The reason for using the lowest value of the control group was that this was the critical value that would indicate the possibility of clinical fracture. The control group included a lowest value of 28.09 Newtons. Since this lowest value just fell within the clinically acceptable strength value of the control group, all the base metal alloy samples with strengths above 28.09 Newtons were accepted as having acceptable strength values. All base metal alloy samples with strength values lower than 28.09 Newtons did not have acceptable strength values. Table 4.2 shows that the lowest values in sample groups A and F were quite close to the 28,09Newtons value of the control group.

In the experimental design the porcelain thickness was increased at regular intervals of 0,3 mm, from 0.7 to 1,6 mm (Figure 4.2). From Figure 4.2 it can be seen that the 1,6 mm base metal ceramic samples, being the thickest, provided more than an adequate increase in strength as all the strengths were above 50.00 Newtons. This indicated the importance of maximizing the porcelain thickness within the 2,0 mm permissible range to provide strength.

Reducing the porcelain thickness to 1,3 mm produced a lower strength value of 28.13 Newtons which was just above the 28.09 Newtons value for clinical acceptability of the control group. This thickness of porcelain was therefore just sufficient to meet the required clinical standard as was set by the control sample group.

Two of the 1,0 mm porcelain samples in Group A had lower strength values (26.75 and 27,81 Newtons) than the 28,09Newton minimum strength requirement set by the noble metal alloy control group for clinical acceptance. This indicated that when the metal alloy was very thin, the minimum thickness of porcelain of in order to match a shade was not thick enough to provide the strength required to meet the clinically acceptable standard.

When the porcelain thickness was reduced from 1,0 mm to 0,7 mm, the strength of the metal ceramic assembly to resist porcelain fracture was virtually halved. In Group E the lowest strength value was only 10.44 Newtons. This indicates that the thickness of porcelain was as important for strength characteristics as it was to meet aesthetic requirements. When reducing the porcelain thickness from 1,3 mm to 1,0 mm the lowest sample strength decreased from 28.13 Newtons to 26.75 Newtons, which was not a very large difference (about 5%). However, when reducing the porcelain thickness from 1,0 mm to 0,7 mm there was a much larger reduction in strength from 26.75 Newtons to 10.44 Newtons (about 60%). This would indicate that not only is 1,0 mm thickness of porcelain necessary to match a shade, but it is also a critical strength factor to resist distortion of thin metal sections that will result in fracture of the porcelain. The 0,7 mm thick porcelain samples were therefore not clinically acceptable in terms of strength requirements or aesthetic requirements for metal ceramic restorations.

Figure 4.2 shows that there was no linear relationship regarding strength values, even though the porcelain thickness was increased linearly and the metal alloy thickness remained constant. This is apparent because although the porcelain thickness variations were linear from one group to the next while the base metal alloy thickness was constant, the strength values between successive groups differed remarkably, increasing unproportionally.

The coefficient of variation (Table 4.2) was relatively comparable, indicating that the manufacturing process of the samples was good.

The statistical method employed was the one way sample Analysis of Variance. This allowed the samples to be compared to the clinically acceptable strength values that were set by the noble metal alloy control group to establish clinical acceptability of sample groups E, A, F and G.

As the porcelain thickness was increased by 0,3 mm between successive sample group (Table 4.2) there was a marked increase in the strength of the samples, indicating that sufficient porcelain thickness of at least 1,0 mm is critically important design principle to utilize in order to gain sufficient strength for metal ceramic restorations.

### *4.1.3 Sub-problem Three*

The results of Sub-problem Three were established by integrating the factors that indicated a change in strength values of the metal ceramic samples when both porcelain thickness and base metal alloy thickness was increased or decreased.

These values for base metal alloys as compared to those of the noble metal alloy control indicated the following:

1. The minimum thickness that the porcelain and metal alloy combination could safely be reduced to and still meet the minimum strength values set by the noble metal alloy control group.
2. The individual minimum thickness of porcelain and the minimum thickness of base metal alloy ratios necessary to maximize strength and aesthetic characteristics for the minimum permissible combination.
3. The individual thickness of porcelain and the thickness of base metal alloy ratios necessary to maximize strength and aesthetic characteristics for metal ceramic restorations that are not subject to minimal space requirements .

The results represented in Tables 4.1 , 4.2 and 4.3 were integrated, in order to allow for the establishment of criteria (Chapter 5) to maximize strength and aesthetic characteristics of porcelain in metal alloy restorations.

The $R^2 = 0.91$ value shown in Table 4.3 indicates the explained variation by the estimated model. This value indicates a 91% explained variation of fractures, revealing that only 9% of fractures could not be explained. The effect of the 11 groups was highly significant ( $P < 0,05$). This indicates that the 11 groups were significantly different from one another.

Table 4.3 Tensile Strengths( in Newtons) of Sample Groups when Porcelain and Base Metal Alloy Thickness was Varied.

| | X-control | | B | | H | | I | | J | |
|---|---|---|---|---|---|---|---|---|---|---|
| | M= 0,3 mm | | M=0,2 mm | | M=0,2 mm | | M=0,3 mm | | M=0,4 mm | |
| | P= 1,0 mm | | P= 1,0 mm | | P=1,6 mm | | P=1,3 mm | | P=1,6 mm | |
| | 1 | 28,09 | 1 | 34,91 | 1 | 63,89 | 1 | 62,95 | 1 | 79,09 |
| | 2 | 37,46 | 2 | 42,75 | 2 | 77,93 | 2 | 60,89 | 2 | 102,20 |
| | 3 | 40,67 | 3 | 39,29 | 3 | 64,97 | 3 | 56,97 | 3 | 85,2N |
| | 4 | 33,50 | 4 | 39,46 | 4 | 53,74 | 4 | 64,99 | 4 | 85,07 |
| | 5 | 35,58 | 5 | 34,15 | 5 | 60,00 | 5 | 67,44 | 5 | 72,32 |
| | 6 | 34,68 | 6 | 31,56 | 6 | 68,28 | 6 | 59,22 | 6 | 66,74 |
| | 7 | 30,97 | 7 | 28,46 | 7 | 67,54 | 7 | 57,74 | 7 | 100,20 |
| | 8 | 34,78 | 8 | 30,59 | 8 | 68,46 | 8 | 58,87 | 8 | 84,40 |
| | 9 | 33,56 | 9 | 37,45 | 9 | 60,32 | 9 | 60,59 | 9 | 85,53 |
| | 10 | 40,16 | 10 | 33,10 | 10 | 62,15 | 10 | 47,74 | 10 | 101,90 |
| | 11 | 37,02 | | | | | | | | |
| | 12 | 41,66N | | | | | | | | |
| highest | 41,66 | | 42,75 | | 77,93 | | 67,44 | | 102,20 | |
| lowest | 28,09 | | 28,46 | | 53.74 | | 47,74 | | 66,74 | |
| Mean | 35,68 | | 35,17 | | 64,73 | | 59,74 | | 86,27 | |
| Standard Deviation (SD) | 4,01 | | 4,61 | | 6,49 | | 5,33 | | 12,14 | |
| Coefficient of Variation (CV) | 11,24 % | | 13,84 % | | 10,03 | | 8,92 % | | 14,38 % | |

$R^2 = 0.91$ = 91% explained variation of fractures

Figure 4.3 is a graphical representation of strength characteristics of base metal alloy samples where the alloy thickness differed from the constant 0,1 mm thickness of Sub-problem Two and the porcelain thickness differed from the constant 1,0 mm thickness of Sub-problem One. The strength values of all 10 samples for each sample group are shown. The results were compared with the clinically accepted standard of the control group ( Table 4.3). The lowest value in the control group was 28.09 Newtons. Since this lowest value just fell within the clinically acceptable strength value of the control group. All the base metal alloy samples with strengths above 28.09 Newtons were accepted as having acceptable strength values. All the base metal alloy samples with lower strength values than 28.09 Newtons did not have acceptable strength values.

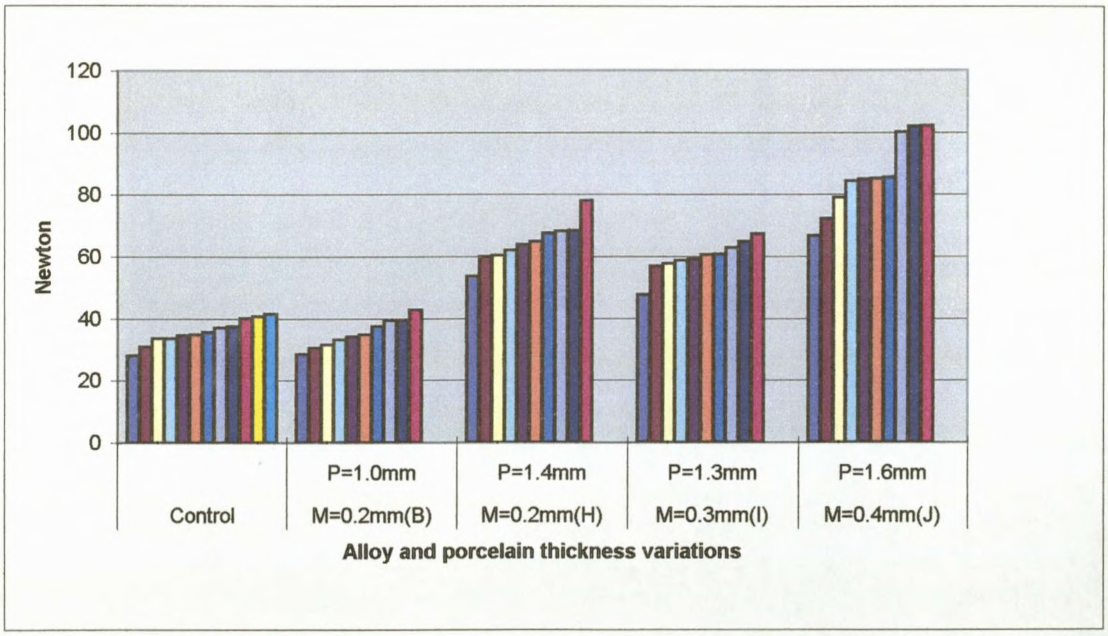


**Figure 4.3 Strength values after variation of porcelain and base metal alloy thickness in 40 samples of Group B, H, I and J**

The coefficient of variation (Table 4.3) was comparable, indicating that the manufacturing process of the samples was good.

The statistical method employed was the one- way sample Analysis of Variance. This allowed the samples to be compared to the clinically acceptable strength values that were set by the noble metal alloy control group to establish clinical acceptability of sample groups B, H, I and J.

The groups H, I and J produced lowest strength values of above 40.00 Newtons and strengths up to 102,00 Newtons. This indicates that where there is sufficient space for both the metal alloy and porcelain. The strength of the restoration can virtually be increased by two or three times depending on the available space and design used.

The results from Group B (Table 4.3) indicate that the minimum thickness that base metal ceramic restorations required to obtain at least the same strength values as the control group, was 1,2 mm. This was 0,1 mm thinner than the control group samples of 1,3 mm thickness, and was possibly due to a reduction in the thickness of the base metal alloy by 0,1 mm. noteworthy, a reduction of metal from 0,3 mm in the noble metal alloy control group to 0,2 mm in the base metal alloy group, allowed in a permissible 33,3333% reduction in metal when using a base metal alloy. The porcelain thickness added the remaining 1,0 mm to make up 1,2 mm. The lowest strength value obtained in group B was 28,46 Newtons.

Reducing the metal alloy to 0,1 mm required at least 1,3 mm of porcelain, as was observed in Group F ( Table 4.2), in order to obtain the clinically acceptable standard of strength of 28.13 Newtons. Although this substantiates Weiss (1983) observation that the metal alloy can safely be reduced to 0,1 mm, there was more benefit in gaining space and improving strength by increasing the base metal alloy to 0,2 mm and reducing the porcelain thickness to 1,0 mm. This resulted in a lowest strength of 28,46 Newtons, and a 0,1 mm reduction in space requirements with the porcelain still being thick enough to match a shade. The slight reduction in base metal alloy therefore had a slightly larger benefit to strength characteristics than reducing the porcelain thickness slightly.

The impact of porcelain thickness compared to alloy thickness regarding strength values is shown in Table 4.3 and Figure 4.3. Groups H and I had overall thicknessess of 1,8 mm and 1,6 mm respectively and the porcelain to alloy ratios differed to the extent that group H had 0,1 mm reduced alloy and increased porcelain while group I has reduced porcelain and 0,1 mm increased alloy. Since group H had higher strength values in resisting the fracture of porcelain during tensile testing conditions, it shows that once the desired 0,2 mm base metal alloy thickness had been obtained, the strength increased more by increasing the porcelain thickness to 1,6 mm in group H, rather than increasing the metal alloy thickness by the same amount. This 33.33% reduction of alloy from 0,3 mm to 0,2 mm was much larger than the 7.14% reduction in porcelain from 1,6 mm to 1,3 mm. However, that slight increase in porcelain percentage allowed more benefit to the overall strength of the assembly than the negative consequences of reducing the alloy thickness. The increase in porcelain thickness therefore had a slightly larger benefit to the strength of the metal ceramic assembly in Group H than the same increase in thickness of base metal alloy in Group I since the low mean and high values were all slightly higher.

# CHAPTER FIVE

## *DISCUSSION*

### 5.0 INTRODUCTION

The purpose of this study was to investigate the performance of base metal alloy ceramic specimens with reference to variations in thickness in metal and porcelain in order to establish criteria to maximize strength and aesthetics in restorations. Generalization of the results are limited by the experimental phase of the study, relatively small sample groups, design limitations and variations of the coefficient of variation in a few sample groups. However, the results provide support of the hypotheses presented for Sub-problems One, Two and Three.

With due consideration to certain assumptions and delimitations, the results produced a sufficient foundation from which to establish strength and aesthetic characteristics to maximize strength and aesthetic characteristics of metal ceramic restorations.

### 5.1 THE ROLE OF BASE METAL ALLOYS IN METAL CERAMIC RESTORATIONS

According to Tucillo and Cascone (1983), base metal alloys are used more extensively than any other metal ceramic alloy globally.

In Sub-problem One the base metal alloy thickness was varied by 0,1 mm increments from 0.1 to 0,4 mm while the porcelain thickness remained constant at 1,0 mm for all four sample groups tested. This was done in order to establish strength characteristics of base metal alloys.

It was hypothesized that a linear relationship existed between metal alloy thickness and force required to fracture the metal alloy, and that a critical force value needed to fracture porcelain could be identified for each metal alloy thickness. Although a critical force value falling in the lower tensile test results of each sample group could be established, a linear relationship did not exist between the thickness of the samples and their ability to resist fracture (Figure 4.1). However, the objective of establishing strength characteristics of metal ceramic alloys was achieved, and the hypothesis consequently partially accepted with the provision that in-between sample strengths could not be accurately predicted.

### *5.1.1 TENSILE STRENGTH DETERMINATION*

Leedy (1985) states that "measurement is quantifying any phenomenon". The unit of measurement used in this study was Newton. Using these measurable values, the strength of the base metal samples to resist fracture could be compared to those of the clinically accepted standard of values set by the noble metal alloy control group.

The Instron 44 testing machine allowed measurements of the tensile strengthsof samples in Newtons, which produced accurate, valid results. The accuracy of the testing machine acting on at least 95% confidence level made it possible to record very small deviations of 0.01 Newtons within the base metal alloy samples for thickness variations, as well as establishing significant differences between certain sample groups.

The one way Analysis of Variance ( ANOVA) was used to compare the test data of base metal alloy samples with those of a clinically acceptable control group.
The results indicated whether the hypotheses in this investigation could be accepted or not.

For Sub-problem One, the control group gave a mean strength of 35,67 Newtons, a lowest strength value of 28,09 Newtons and a highest strength value of 41,60 Newtons. In this study the lowest value of the control group was used as it wasthat the critical strength value that would indicate any possibility of clinical fracture. The control group indicated a lowest strength value of 28.09 Newtons. Since this lowest value just fell within the clinically acceptable strength value of the control group, all the base metal alloy samples with strengths above 28.09 Newtons were clinically acceptable strength values. Whereas base metal alloy samples with strength values lower than 28.09 Newtons did not have clinically acceptable strength values. Table 4.1 shows that the lowest value of each of the sample groups A, B, C and D was always slightly closer to the control group than the highest values.

### *5.1.2 TENSILE STRENGTHS FOR BASE METAL ALLOY THICKNESS VARIATIONS*

The value of using the Instron 44 testing machine was in being able to quantify strength measurements in Newtons for the ability of the base metal alloy and noble metal alloy control group samples to resist porcelain fracture. The quantified values of the base metal alloy samples could then be compared to the clinically accepted values set by the control group in order to establish whether the base metal alloy samples complied with this standard of clinical acceptability.

In the experimental design the metal alloy thickness was increased at regular intervals of 0,1 mm, from 0.1 to 0,4 mm. The 0,4 mm base metal alloy samples, being the thickest, provided more than an adequate increase in strength as all strengths were above 40.00 Newtons and thus much higher than the 28,09 Newtons standard set by the control group. This indicated the importance of maximizing the base metal alloy thickness in providing strength for porcelain support.

The 0,2 mm and 0,3 mm alloy samples also showed strength values above that of the control group's lowest value of 28.09 Newtons with the 0,2 mm base metal alloy's lowest value being 28.46 Newtons and the 0,3 mm samples having a lowest value of 32.21 Newtons. Figure 4.1 therefore illustrates that clinically acceptable strength values had been achieved.

The 0,1 mm samples had a lowest strength value of 26.75 Newtons, and were not strong enough to meet the required minimum strength requirement of 28,09 Newtons set by the noble metal alloy control group. These samples did not meet the clinically acceptable standard.

The results in Table 4.1 show that increasing the metal alloy thickness increased the metal ceramic restoration and porcelain strength markedly. Maximizing the alloy thickness as far as possible is an important requirement. However, this is not always possible due to space requirements. As a result, if the porcelain thickness is at the minimum 1,0 mm permissible thickness to match a shade. The alloy should not be reduced to below 0,2 mm. This does however allow a reduction of 0,1 mm from the thickness requirement set for clinical acceptability by the noble metal alloy control group of 0,3 mm, which results in a 33.33% permissible reduction.

### *5.1.3 FACTORS INFLUENCING BASE METAL ALLOY DESIGN FOR METAL CERAMICS*

Shillingburg (1997:93-97) states that the law of beams applies to metal ceramic bridges. Since the base metal alloy samples tested for thickness variations in Sub-problem One conformed to the design specifications that in turn complied with those of a beam, predictable results could be expected when considering the law of beams. However, when the base metal alloy thickness was increased by equal increments of 0,1 mm (Figure 4.1), overlapping of results between the sample groups A, B, C and D and an unproportional change in strength values between the groups resulted. These results were very significant in showing that the deviation of predictable results was not due to the homogenous base metal alloy composition of the metal ceramic restoration, and therefore must be explained due to additional design components resulting in unpredictable failure as a result of:

1. The porcelain component of the restoration.
2. The bond component between the base metal alloy and porcelain.
3. Both 1 and 2 above.

For the purpose of this study the bond strength was assumed to be consistent since the bonding technique utilized for all samples was consistently applied, and the Wiron 99 (Bego, Germany) base metal alloy used was combined only with one brand of porcelain (Argen, Johannesburg). The porcelain characteristics of the restoration may therefore be important in explaining the unpredictable nature of fracture patterns established between the sample groups (Figure 4.1). The characteristics of porcelain fall under Sub-problem Two and will be dealt with in Section 5.2. Although in between test sample strength values could not be predicted with complete certainty, definite strength patterns are observable in Figure 4.1 for each sample group.

The results could be used to determine the characteristics of base metal alloy, with the concomitant ability of porcelain to resist fracture in base metal ceramic restorations. What did appear significant (Figure 4.1), was that there was not a very large variation in strength values between the 0,1, 0,2 and 0,3 mm thick sample groups. The noble metal alloy control group was used to establish clinically acceptable standards for strength measurements. This gave a measurable value of 28,09 Newtons. By comparing the measured strength values of base metal alloy in the same Newtons units, those samples that did not meet the clinically accepted standard could be identified. The 0,1 mm thick base metal alloy sample group had two samples that showed lower strength values than that of the clinically acceptable control group. The two 0,1 mm base metal alloy samples that were below clinically acceptable standards showed strengths of 26,75 Newtons and 27,81 Newtons respectively, which were very close to the 28,09 Newtons value of the control group. They also showed such a similar distribution pattern to the 0.2 and 0,3 mm sample groups that reducing the metal alloy from 0,3 to 0,1 mm appeared to have very little significance in reducing the overall strength of the metal ceramic assembly as long as there was sufficient depth of porcelain.

However, these two samples of 26,75 Newtons and 27,81 Newtons that were below the clinically accepted standard regarding strength requirements cannot be ignored. There were also indications that the 0,1 mm thick alloy samples allowed distortion of the metal substrate during working and firing procedures. As a result it is not recommended that the base metal alloy substructure be reduced to 0,1 mm. It must however be noted that reducing the metal alloy thickness from 0,3 to 0,1 mm did not result in a large reduction of strength values even though the 0,1 mm thick samples group showed two indicated some values that were just below the 28,09 Newton value of the control group.

Table 4.1 shows the coefficient of variation values that were based on the Standard of Deviation for each sample group. The importance of these values was that they indicate the quality of manufacture of the samples. The lower the coefficient of variation, the higher the quality of manufacture. Furthermore, the quality of manufacture was influenced by the amount of material available to work with. This study illustrates the problems of working with space constraints. The 0,4 mm base metal alloy samples showed a definite increase in strength value when compared to the 0,1, 0,2 and 0,3 mm samples which were more similar to each other. The 0,4 mm sample group also showed a much smaller coefficient of variation(CV) of only 3.19% as compared to a CV of 10.96% and above for the 0,1, 0,2, and 0,3 mm sample groups respectively (Figure 4.1). This indicates that if a minimum of 0,4 mm base metal alloy thickness is allowed for the alloy thickness, the restoration will be able to resist porcelain fracture better and with a smaller standard of deviation. Therefore, 1,4 mm of space would be required to be able to start producing more predictable results and hopefully reduce the percentage of unexplained clinical fractures. The 0,4 mm base metal alloy samples provided more than an adequate increase in strength as all the strength values were above 40.00 Newton. This indicates the importance of maximizing the base metal alloy thickness where space allows.

Yamamoto (1985:18-26) indicates the importance of maximizing the alloy thickness as far as possible. The results of this study coincided with recommendations made by Yamamoto (1985), in that the metal alloy should be as thick as possible in order to maximize strength since the coefficient of variation is the lowest, being only 3.19%, for the 0,4 mm base metal alloy sample group. Any reduction of alloy thickness to allow for space for porcelain therefore is assumed to reduce the strength of the assembly and the quality of manufacture. Although Yamamoto's argument is correct in terms of the present results, it may not be possible to achieve this in every situation due to space constraints.

Where a reduction of base metal alloy is necessitated due to space constraints, a greater amount of base metal reduction is permissible than the minimum of 2,92 mm that Yamamoto theorized. Base metal alloys can safely be reduced to 0,2 mm and still provide sufficient strength values to surpass the clinically accepted 28,09 Newton values set by the noble metal alloy control group even though the producibility is more inconsistent. The permissible reduction of base metal alloy for Sub-problem One, however, did not allow a reduction of up to 0,1 mm, as has been suggested by Weiss (1983), as the minimum strength values of two samples were below that of the clinical standard of the control group. These 0,1 mm base metal alloys were also observed to distort due to working and firing procedures and are therefore not recommended for practical use.

From Sub-problem One and the results obtained it is argued that the alloy thickness is the main contributing factor for enhancing the strength of metal ceramic restorations, and that the alloy thickness needs to be as thick as possible when the porcelain thickness is at a minimum of 1,0 mm in order to just be able to gain satisfactory reproducibility in strength and aesthetics (Kersten, 1988:383).

Since the goal of this study was to maximize strength and aesthetic characteristics, reducing the base metal alloy thickness below 0,1 mm is not advocated as this did not comply with the minimum required strengths established by the control group. However, it cannot be said with certainty that reducing the metal alloy to 0,1 mm will result in fracture, since failure may depend on design and occlusal function.

Although Yamamoto's ( 1985) argument is correct in terms of the present results, the following problems may appear as the alloy thickness is increased:

1. A reduction of space to meet aesthetic demands for porcelain.
2. A possible increase in casting distortion.
3. A possible increase in casting porosity.
4. Increased cost of metal alloy.
5. Thicker metal alloy sections cool slower resulting in a possible increase in the coefficient of thermal expansion mismatch between alloy and porcelain on cooling which may result in porcelain fracture.

The advantages of maximizing alloy thickness are:

1. Castability in preventing miscasts of thin alloy areas.
2. Improved strength to the alloy substructure.
3. Improved support for porcelain where more than adequate space is realized, thereby increasing porcelain strength.

The most important benefit of increasing or decreasing the thickness of the alloy depends on the availability of space. If there is not enough space it is difficult to meet strength and aesthetic demands and one or the other needs to be sacrificed in order to gain optimal results (Kersten, 1988).

Where there is sufficient space available, indications from the first Sub-problem are to maximize the alloy thickness as soon as there is sufficient porcelain depth for aesthetics.

From the results it would appear that less than 1,2 mm of available space is insufficient to obtain the required strength and aesthetic characteristics and that application of porcelain in such thin areas should rather be avoided so that the metal alloy can be maximized to ensure sufficient strength, at the cost of any aesthetic benefits. Should the strength be insufficient and the restoration fracture, the aesthetics will be lost in any case. The question also needs to be asked if a restoration just covered by opaque is aesthetically more acceptable than one designed with a shiny metal occlusal bite even in base metal alloy.

Due consideration may be given to different areas of occlusal forces in the mouth, not dealt with in this study. However, according to clinically proven recommendations, at least 0,2 mm of alloy thickness of base metal alloy is required for adequate support for the porcelain, and since less than 1,0 mm porcelain will not effectively match a shade, aesthetics has to be compromised when the preparation allows for less than 1,2 mm space for both alloy and porcelain.

### *5.1.4 IMPLICATIONS OF AVAILABLE SPACE DUE TO PREPARATION DESIGN*

#### 5.1.4.1 DESIGN CRITERIA

Due to the shape of a preparation for metal ceramic restorations, there are different amounts of space available for variations of alloy and porcelain at different areas of the restoration. Section 2.3 dealt with ideal tooth preparations.

The reduction of tooth structure should ideally be at least:

1. 1,2 mm at the margins.
2. 1,5 mm at the middle third of the crown.
3. 2,0 mm at the cuspal area.

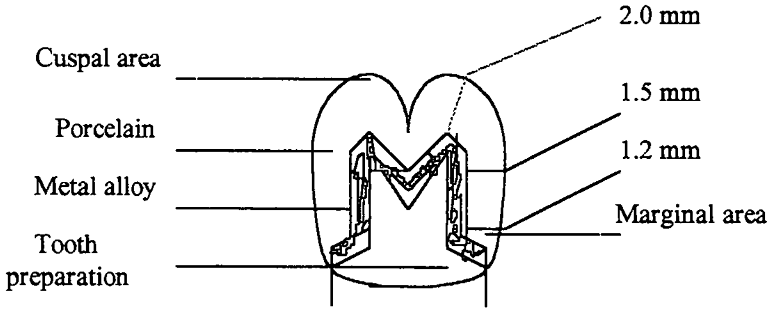


***Figure 5.1 Hypothetical tooth indicating the zones where available space for porcelain thickness varies.***

The recommended alloy and porcelain thickness ratios may be applied to these areas.

It is possible to provide sufficient space for porcelain at porcelain margins by preparing a but 90° or deep chamfered preparation. However, beveled margins not acceptable for metal ceramic crowns are often employed. These beveled margins allow less space proportionately to the increase in the angle of the bevel.
Theoretically, beveled margins increase the marginal seal, improving the longevity of the restoration, but practically many aspects such as distortion of thin alloy sections, inadequate space availability, combined with the increased demand for the ability of the dental technician to reproduce accurate thin sections in alloy and porcelain, prevent this design from being optimal (Yamamoto, 1985:495-514).

Even with ideal margin preparations, marginal space is the most restricted and relate to the minimum accepted requirements of 1,0 mm. However, the interactive relationship between aesthetics and thickness of porcelain required can never be ignored. As the available space for porcelain and alloy decreases, the base metal alloy thickness must decrease in order for acceptable porcelain depth and aesthetics to be maintained, resulting in the recommendation to reduce the alloy thickness to the minimum of 0,2 mm. Such a recommendation is further enforced by the higher demands for aesthetics at the margins. As a result it is necessary to cut the metal back at least by 1,0 mm resulting in at least 1,0 mm porcelain thickness that is necessary to match a shade (Kersten 1988:383).

In areas where metal collars are utilized there may be a small area where the porcelain finish is thinner than 1,0 mm. The design of the metal alloy to porcelain finish line should be at 90° to each other to allow the porcelain to end with the maximum porcelain thickness permissible. This finding supports that by Yamamoto (1985:54-59) who stated that all metal / porcelain junctions should be at 90°. Even with a metal collar the porcelain may become thinner at the metal porcelain junction of the metal collar. If the porcelain thickness were below 1,0 mm this study's results would support the findings of Gardner *et al.* (1997), who indicated that metal ceramic restorations with a porcelain margin resisted greater loading before fracture than those restorations with metal collars. That is why the design is so important. The results of this study are supported by Gardner *et al.* ( 1997), who indicated that the porcelain thickness had slightly higher benefits for strength characteristics than metal alloy thickness when metal ceramic design criteria are adhered to with at least 0,2 mm of base metal alloy thickness (Table 4.3 Group H and I).

According to Yamamoto (1985:27-46), an even thickness of porcelain is desirable, and the alloy thickness needs to vary, being thin at the margins and thickest at the cusp tips in order to support an even porcelain thickness as far as possible. This results in weak marginal areas in a restoration, rendering it more susceptible to fracture.

As the available space increases from the margin to the cusp tip, the strength must be increased by increasing the metal alloy thickness. Should the marginal design not allow sufficient space for adequate metal and porcelain depth, the aesthetics of the margin may need to be sacrificed to ensure sufficient strength to resist fracture of thin porcelain sections since there will not be sufficient space for at least 0,2 mm base metal alloy and 1,0 mm porcelain. This will result in both strength and aesthetic results being unacceptable (Yamamoto, 1985:495-513).

Porcelain shoulders that do not have sufficient space for porcelain coverage cast a deep gray metal shade around the margins regardless of the alloy used, but are far more pronounced in base metal alloys due to the darker, thicker oxide formed. If there is insufficient space available for porcelain this will result in a reduction of aesthetics, whether a thin metal collar is utilized or not, since the metal alloy needs to be brought close to the margin to support the thin porcelain sections in this area. There is also a tendency to build these porcelain sections thicker due to space constraints, which results in an incorrect tooth shape in this area. Besides the difficulty the dental technician may experience in obtaining an accurate marginal seal, the incorrect emergence profile of the restoration from the margin may interfere with the natural gum position. This may result in incorrect pressure to the gums, which may lead to irritation, inflammation and retraction of this tissue. It is not the purpose of this study to explain the results that may proceed due to gum disease, except to note that good healthy gums are synergistic to good healthy teeth.

### 5.1.4.2 PERFORMANCE CHARACTERISTICS

The findings of Sub-problem One, showed that 0,1 mm alloy thickness was too thin to recommend for routine practical use. Fracture of porcelain due to alloy distortion, must be considered. However, Weiss (1983) indicates that in 4500 crowns this was routinely done with a fracture rate of only 1%, which initially seemed to be contradictory with the results of this study.

The reasons for discrepancies between this study and that of Weiss (1983) may be as follows:

DESIGN

The limitation of the design used in this studies laboratory specimens may have reduced the strength markedly from the normal shape and design of metal ceramic crowns in practice, as has been stated in the delimitations of this study.

PORCELAIN THICKNESS

The thickness of porcelain may have been increased above the minimum of 1,0 mm in order to realize sufficient strength. This could only be verified in Sub-problems Two and Three, as increased porcelain thickness was not dealt with in Sub-problem One.

CEMENTATION

Cementation of the restoration would further enhance its strength, giving added support to the alloy substructure, thereby giving the alloy additional strength and preventing alloy distortion to the degree that the porcelain will not fracture.

However, the increase in strength to the restoration due to cementation techniques was not dealt with in this study and may be determined in a future study.

LOCALITY OF THIN SECTIONS

The amount of occlusal forces thin base metal alloy sections are subjected to may determine the permissible thickness of base metal alloy. Porcelain at the margins are not exposed to direct forces of occlusion, as a result the porcelain may not fracture even though the base metal alloy is reduced to 0,1 mm.

PRACTICAL SIGNIFICANCE

Although the 1,0 mm porcelain samples showed a lowest value of 26,75 Newtons, which was below the clinically acceptable control of 28,09 Newtons, the value difference was so small that it may have been insignificant in practical terms.

There was therefore sufficient evidence to support Weiss (1983) clinical observations. In fact, some long span metal ceramic bridges are only possible due to the superior properties of base metal alloys regarding modulus of elasticity which is almost twice that of noble metal alloys (Bertolotti, 1988: 82). They also possess a higher resistance to sag and creep during firing procedures because they generally possess higher melting ranges than noble metal alloys (Bego System catalogue, undated). They may however show inferior properties with regard to biocompatibility and resistance to tarnish and corrosion (Geis-Gerstorfer, *et al.,* 1994). The advantages and disadvantages therefore need to be weighed against each other during the specific treatment plan for a specific patient. Where a very long span bridge is advocated there might be no other alternative than to use base metal alloy restorations, providing the patient is not sensitive to any of the alloy components.

Due consideration needs to be given to the properties of base metal alloys for restorations where noble metal alloys can be utilized, because base metal alloys tend to produce a colder, grayer coloured restoration especially in the marginal areas where the metal colour shines through the translucent tooth structures. This together with reduced corrosion resistance (Section 2.1.1) does not make it an ideal restorative material. However, these alloys are used more extensively than any other metal ceramic alloy, purely because of financial cost benefits. Although the purpose of this study was to investigate the strength and aesthetic characteristics of base metal ceramic restorations, due consideration needs to be given to the additional aesthetic contributions of noble metal alloys before choosing base metal ceramic alloys as a restorative material for every situation. It may be more beneficial to use noble metal alloys for single anterior metal ceramic restorations due to the higher aesthetic demands and lower forces of occlusion in this area. The use of base metal alloys may be more suitable for posterior bridges where greater forces of occlusion are experienced combined with slightly reduced aesthetic demands.

In view of the role of base metal alloy thickness and its relationship to porcelain strength as shown in the results (Table 4.1), hypothesis One i.e. that a critical force value needed to fracture porcelain could be identified for each metal alloy thickness, can be accepted.

Recommendations regarding the role of base metal alloys in metal ceramic restorations are therefore to maximize alloy thickness while preventing a reduction of alloy thickness to below 0,2 mm.

## 5.2 THE ROLE OF PORCELAIN IN STRENGTH AND AESTHETIC CHARACTERISTICS OF METAL CERAMIC RESTORATIONS

The introduction of porcelain as a dental restorative material was because of its aesthetic properties which allow accurate reproduction of natural tooth shades, translucency and glaze. It also allows sufficient strength to successfully resist fracture and can be bonded to a metal alloy substrate for added strength. These properties together with its ability to accurately reproduce tooth shape and surface characteristics on firing make it ideal as a dental restorative material. Its main drawback is its hardness which may result in excessive wear to the apposing natural dentition. The role porcelain plays regarding aesthetic characteristics is more obvious than its contribution to strength in metal ceramic restorations. The results of this study were important in showing the contribution porcelain thickness had in terms of metal ceramic restorations.

In Sub-problem Two, the alloy thickness was kept constant at 0,1 mm, while the porcelain thickness was varied by 0,3 mm intervals, from a porcelain thickness of 0,7 mm to 1,6 mm.

Regarding the role of porcelain strength, it was hypothesized that a linear relationship between porcelain thickness and the force required to fracture the porcelain existed, and that a critical force value needed to fracture porcelain could be identified for each thickness of porcelain. Although a critical force value in the lower tensile test results of each sample group could be identified, a linear relationship did not exist between the thickness of the samples and their ability to resist fracture.

The objective of establishing strength characteristics of porcelain was still possible, but had to be viewed in the light of certain properties of porcelain that allowed for higher coefficients of variance (Table 4.2). The hypothesis was therefore accepted, with the provision that in between sample value strengths could not be accurately predicted and with due consideration to inconsistent coefficient of variance values due to the properties of porcelain (Section 5.2.2). The practical application of porcelain sample thickness and strength values when compared to the control group was relevant, and could be used to reach the objective of Sub-problem Two.

### *5.2.1 TENSILE STRENGTHS FOR VARIATIONS OF PORCELAIN THICKNESS*

The value of using the Instron 44 testing machine was in being able to quantify strength measurements in Newtons for the ability of the base metal alloy and noble metal alloy control group samples to resist porcelain fracture. The quantified values of base metal alloy samples in which the porcelain thickness was varied ( Group E, A, F and G) could then be compared to the clinically accepted value set by the control group, in order to establish whether these base metal alloy samples complied with the standard of clinical acceptability.

The instron 44 testing machine allowed accurate and valid results to be measured in Newtons. The accuracy of the testing machine acting on at least 95% confidence levels made it possible to record very small deviations of 0,01 Newtons within the base metal alloy samples for any thickness variations, as well as significant differences between certain sample groups. The one way Analysis of Variance test was used to compare the test data of the base metal alloy samples in Groups E, A, F andG with the data of the control group.

For Sub-problem Two, the control group gave a mean strength of 35,67 Newtons, a lowest strength valve of 28,09 Newtons and a highest strength value of 41,60 Newtons. For this study the lowest value of the control group was used as this was the critical value that would indicate any possibility of clinical fracture with 93% predictability. The control group indicated a lowest strength value of 28,09 Newtons. Since this lowest value just fell within the clinically acceptable strength value of the control group, all the base metal alloy samples with strengths above 28,09 Newtons were accepted as having clinically acceptable strength values, whereas base metal alloy samples with lower strength values than 28,09 Newtons did not have clinically acceptable strength values. Table 4.2 shows that the lowest value of each sample group was always slightly closer to the control group.

In the experimental design the porcelain thickness was increased at regular intervals of 0,3 mm, from 0.7 to 1,6 mm. The 1,7 mm base metal ceramic samples in group G being the thickest provided more than an adequate increase in strength as all the strength values were above 50,00 Newtons ( Table 4.2). This indicated the importance of maximizing the porcelain thickness within the 2,0 mm permissible range for providing strength.

When the porcelain was reduced to 1,3 mm the lowest strength value was 2813 Newtons which was just above the 28,09 Newtons value for clinical acceptability of the control group. This 1,3 mm thickness of porcelain was therefore just sufficient to meet the required clinical standard as was set by the control sample group.

The 1,0 mm porcelain samples showed a lowest strength value of 26,75 Newtons, which was not strong enough to meet the required strength requirement set by the noble metal alloy control group for clinically accepted values of 28,09 Newtons. This indicated that when the metal alloy was very thin, the minimum thickness of porcelain of 1,0 mm in order to match a shade, was not thick enough to provide the strength required to meet the clinically acceptable standard.

When the porcelain thickness was reduced to 0,7 mm from 1,0 mm, the strength of the metal ceramic assembly to resist porcelain fracture was virtually halved, and the lowest strength value was only 10.44 Newtons. This indicates that the thickness of porcelain is as important for strength characteristics as it is to meet aesthetic requirements. When reducing the porcelain thickness from 1,3 mm to 1,0 mm the lowest strength values decreased from 28.13 to 26.75 Newtons, which is not a very large difference. However, when reducing the porcelain thickness from 1,0 mm to 0,7 mm, there was a large reduction in the lowest strengths from 26.75 to 10.44 Newtons. This would indicate that not only is 1,0 mm thickness of porcelain necessary to match a shade, but it is also a critical strength factor to resist distortion of thin metal sections that will result in fracture of the porcelain. The 0,7 mm thick porcelain samples were therefore not clinically acceptable regarding strength requirements or aesthetic requirements for metal ceramic restorations.

### *5.2.2 PROPERTIES OF PORCELAIN*

Even when all recommendations are followed, there is still a significant number of clinical failures. This figure is said to be approximately 7% (Yamamoto, 1985).
Jones (1983:127) agrees that unexpected clinical failures still occur, and that predictability of metal ceramic restorations cannot be determined with certainty.

This study showed a 9.3% unpredictability (Table 4.3), which was similar to Yamamoto's 7% of unexplained clinical fractures. It is therefore necessary to first discuss the relevant factors related to porcelain's properties and its unpredictable nature, before entering into a discussion regarding the results of this study as pertaining to characteristics of porcelain. The reason for this is to create an awareness that even when all the ideal criteria appear to be implemented, a small percentage of failure is still possible due to the nature of porcelain.

The following factors apply to porcelain fracture:

- The first is the presence of flaws that reduce measured strength values in the brittle glass-like material 100% to 1000%, from the theoretically possible strengths that should be obtained. Since these flaws appear randomly there control measures are limited in order to ensure predictability. In glass these flav are particularly destructive if they appear at the surface. These flaws may be reduced to a large extent porcelain by creating a glaze on the outer surface. However, due to the method of fabrication, dental porcelain materials for metal ceramics are as reliant on bulk texture imperfections as surface defects (Jones, 1983 : 100). These flaws also propagate readily into cracks from flaws at the metal alloy to ceramic bond interface, especially if the bond is not strengthened adequately .

- Inconsistent and possibly insufficient condensation of the porcelain mass may also result in unpredictable results. Techniques used to assist with condensation include: vibration of the particles once mixed with liquid either by a tapping action or vibration with the end of a Le Cron carver or ultrasonic vibration, to mention a few techniques . It is however not possible to control the degree of condensation accurately (Yamamoto, 1985: 450). The term 'no condensation' would mean that the porcelain would be built up using a brush or spatula and paper tissue to absorb the liquid without any vibration or pressure being applied to the porcelain. The technique employed in this study was to apply porcelain into a mould with a brush and then to compress the porcelain with a tissue and finger pressure into the mold before carefully removing the metal alloy and porcelain onto which it had been compressed with the use of a plunger resulting in little condensation. This was to get more consistent results as it would be more difficult to keep the amount of condensation the same if condensation techniques were used.

- The firing shrinkage of porcelain results in approximately 40% reduction in volume after firing and it may be reduced by effective condensation to nearly only 20% .This results in a reduction of internal porosity and internal and external flaws. Since dental porcelain manufacturers supply porcelains with mixing particles of several sizes, the firing shrinkage is reduced to 20%- 30% (Yamamoto, 1985:454). As a result many dental technicians do not make use of any condensation techniques, especially the ultrasonic vibration technique which has been considered to be the only technique to significantly increase the strength of porcelain (Yamamoto, 1985: 451) .

- Faults due to porosity reduce the total cross sectional area over which a force is applied, thus creating stress concentrations in the porcelain. Normal feldspathic porcelain is not weakened significantly if the porosity is regular, such as when firing without vacuum. However, if the porosity is irregular, such as in porcelain with a high aluminium content, it will be affected.

- The coefficient of thermal expansion is related to crystal formation of leucite crystals and is not consistent with successive bakes, changing unpredictably to either a higher or lower expansion than the previous bake. After several bakes the porcelain tends to devitrify and reverts into a glass-like phase with a more consistent coefficient of thermal expansion.

- The time dependent reduction in strength of porcelain is referred to as "static fatigue" and is believed to be influenced by the moisture content of its environment. This limits its load bearing capacity, and reduces predictability even more especially regarding in vitro studies. Appropriate glazing of the external surface may reduce the rate of fluid absorption and assist in prolonging the life of the ceramic material.

- The unpredictability and high variance in standard deviation are further complicated by the bonding process of porcelain to a metal alloy substructure. There is still uncertainty as to the precise mechanism of metal ceramic bonding (Jones, 1983:124). The reason for inconsistent oxide formation necessary for chemical bonding, especially in base metal alloys, still needs to be established. Any absorbed carbon or water vapor significantly reduces wetting of the metal alloy with porcelain and will produce inconsistent bond strengths (Jones, 1983:125) .

As a result of the lower confidence in accurate predictions related to strength values for porcelain, many authors advocate the need to maximize strength by applying recommended design principles. Authors such as Yamamoto (1985:1-100) stress the need for increasing the thickness of the metal alloy thickness to a maximum.

As a result of the above factors, porcelain is not a completely predictable material regarding fracture values for a specific design. Moreover, coefficient of variant values can be expected to vary consistently as demonstrated in this study.

The metal ceramic design in this study was a very limiting factor since it did not maximize compressive stresses. The design corresponded with flat areas such as porcelain margins where consistent results would be difficult to achieve, as apposed to occlusal areas which consist of curved alloy support areas. Notwithstanding the design limitations, the significant difference between the groups created an excellent model for predictability as was expected. As a result recommendations could be made. There was a range of strength values from 51,79 Newtons to 102,20 Newtons, when varying the total thickness of the metal ceramic sample from 1,7 mm to only 2,0 mm. The increase of thickness of only 0,3 mm, which was a very small increase in total thickness of the metal ceramic samples resulted in large strength variations of 50,41 Newtons. This was significant in indicating the large strength variations that may result with small variations of alloy thickness.

### *5.2.3 DESIGN CONSIDERATIONS FOR PORCELAIN THICKNESS OF METAL CERAMIC RESTORATIONS*

Good strength characteristics are influenced by porcelain shrinkage which depends on how densely the porcelain particles are packed. The porcelain thickness influences the amount of shrinkage and the type of stresses induced in the porcelain after it has been fired. Thin sections of porcelain do not produce the desirable compressive stresses that allow porcelain strength to be increased. The thicker the porcelain, the greater the shrinkage and compressive stresses induced. However, when porcelain thickness becomes too large, and is unsupported, the compressive range diminishes drastically as a depth of 2,0 mm of porcelain is reached or exceded, resulting in weaker tensile or shear forces that may result in fracture (Yamamoto, 1985:189-190) (Figure 5.1).

An oval design with full porcelain coverage would also increase the compressive stresses within the porcelain, thereby strengthening the restoration further. However, cracking due to overcompression is also possible if the compressive stresses become too excessive. Cracking due to tensile stresses in porcelain however occurs more readily, as this weakens the porcelain the most (Yamamoto, 1985:160-168).

As the porcelain thickness increases, there is a possible increase in Griffith flaws and other micro irregularities( Jones, 1983:100). This may explain why, even though the strength increased significantly as the porcelain thickness was increased, the coefficient of variation values also increased (Table 4.2).

Table 4.2 shows the four sample groups E, A, F, and G. Distribution values within sample groups can be seen as well as a comparison of sample groups. Each sample group shows a similar distribution pattern though variations in coefficient of variance values are observed.

Group A indicates slightly more consistent results, though the mean deviation was still not as low as that of the samples where the alloy thickness was varied (Table 4.1).

Since there was such a variation within the sample groups themselves, the fracture strengths of porcelain bonded to a metal alloy substrate could not be accurately predicted for various thickness of the porcelain when the alloy thickness remained constant, and a pattern representing a range of strength values was observed (Table 4.2). As a result, although increasing the porcelain thickness resulted in mean strength increases, it was not possible to predict with certainty that the 1,3 mm thick porcelain samples would definitely resist fracture of the porcelain better every time than the 1,0 mm thick porcelain samples. Figure 4.2 shows that although the overall strength was improved, some samples from the 1,3 mm thick porcelain samples did not resist fracture as well as the 1,0 mm thick porcelain samples.

Accurate predictability was therefore not possible, except to say that the 1,6 mm porcelain samples were stronger than the 1,0 mm porcelain samples in each instance. It can therefore be argued that porcelain needs to be increased in thickness to a reasonable extent to ensure success, but obviously not beyond the 2,0 mm range, which is the maximum thickness advocated for porcelain regarding strength values. What was however significant, was that the range of strength values was very large as porcelain thickness changed, indicating the significant role that porcelain thickness plays in allowing acceptable strength values in metal ceramic restorations.

### 5.2.3.1 PORCELAIN THICKNESS VS STRENGTH CHARACTERISTICS

Strength characteristics are directly influenced by the available space for porcelain thickness. Should there be more than sufficient space, maximizing of strength and aesthetic characteristics would not pose a problem.

The 1,6 mm thick porcelain samples provided more than an adequate increase in strength as all the samples had strengths above 50.00 Newtons. This indicated the importance of maximizing the porcelain thickness within the 2,0 mm permissible range.

Reducing the porcelain thickness to 1,3 mm showed a lowest strength value of 28,13 Newtons which was just above the 28,09 Newtons value of the control group. This thickness of porcelain was therefore just sufficient to meet the required clinical standard as was set by the control sample group.

The 1,0 mm porcelain samples had a lowest strength value of 26,75 Newtons, and were not strong enough to meet the strength requirement set by the noble metal alloy control group. This indicated that if the metal alloy was too thin, the minimum thickness of porcelain of 1,0 mm in order to match a shade would not be thick enough to provide the strength required to meet the clinically acceptable standard; hence additional porcelain thickness was needed.

When the porcelain thickness was reduced to 0,7 mm from 1,0 mm, the strength of the metal ceramic assembly to resist porcelain fracture was more than halved, with a lowest strength value of only 10,44 Newtons. This indicates that the thickness of porcelain is as important for strength characteristics as it is to meet aesthetic requirements.

When reducing the porcelain thickness from 1,3 mm to 1,0 mm, the lowest strength decreased from 28,13 to 26,75 Newtons, which was not a significantly large difference. However, when reducing the porcelain thickness from 1,0 mm to 0,7 mm, there was an unacceptably large reduction in strength from 26,75 to 10,44 Newtons. This observation is most significant as it would indicate that not only is 1,0 mm thickness of porcelain necessary to match a shade, but it is also a critical strength factor to resist distortion of thin metal sections that will result in fracture of the porcelain.

The 0,7 mm thickness of porcelain showed greatly reduced strength values well below clinically acceptable standards, unlike the 1,0 mm sample group which only had two samples just slightly below 28,09 Newtons.

Only porcelain sample groups of 1,3 mm or above met the required clinical strength values of the control group. As a result, indications of a critical thickness of porcelain between 0,7 mm and 1,0 mm were observed. Since this value was below 1,0 mm thickness of porcelain, which is the minimum thickness of porcelain required according to the criteria already established, it was deemed unnecessary to establish the exact critical value.

By increasing the base metal alloy thickness from 0,1 mm to 0,2 mm, the porcelain thickness could be successfully reduced to 1,0 mm (Table 4.1). This is supported by Kersten (1988:383) who states that this is the minimum permissible thickness to match a shade. Moreover, 1,0 mm porcelain thickness is not only the minimum thickness necessary for aesthetic reasons, but for resisting fracture as well.

### 5.2.3.2 DISADVANTAGES OF INCREASING PORCELAIN THICKNESS

Although the strength of porcelain increased significantly as the thickness increased, the standard of deviation also increased. This resulted in approximately a 9% phenomenon of cracking in porcelain that could not be accounted for. This figure coincided with clinically unexplainable fractures in restorations (Yamamoto, 1985). The standard of deviation increased from 3,41 Newtons where porcelain was 0,7 mm to 7,13 Newtons where porcelain was 1,6 mm thick. This indicates that manufacture consistency decreased as porcelain thickness increased. The strength benefits were much greater, with thick porcelain sections having strength values well above the clinically acceptable strength values of the control group. Since design factors also influence predictability, the delimitations regarding variations of design in this study were also considered.

The disadvantages of increasing porcelain thickness are:

1. Possible strength reduction occurs in porcelain due to unsupported areas resulting in tensile or shear cracks.
2. Increase in Griffiths flaws increasing coefficient of variation of strength values.
3. Possible increase in porosity and air in the porcelain that may not be completely eliminated by vacuum firing.

#### 5.2.3.3 THE ADVANTAGES OF INCREASING PORCELAIN THICKNESS

The advantages of increasing the porcelain thickness to its maximum recommended thickness are:

1. Aesthetic demands are met and aesthetic appearance increases as the porcelain depth is increased.
2. An increase in the compressive strength of the porcelain occurs.
3. The compressive bond from porcelain on the metal alloy increases.
4. Slower cooling of the porcelain may reduce the coefficient of thermal expansion mismatch between the metal alloy and porcelain.

As long as there is sufficient bulk of porcelain, the alloy may be reduced to its minimum thickness, and there will be more than sufficient strength and aesthetic characteristics. This may explain why it was possible for Weiss (1977) to obtain only 1% failure of crowns in a study of 4 500 units that were routinely reduced to a metal thickness of 0,1 mm and even lower in some instances. The success Weiss achieved may be attributed to good preparation design principles that allowed an increase of porcelain thickness above the minimum required thickness, thereby increasing strength to acceptable levels while obviously improving the aesthetics of the restoration, allowing more desirable results.

#### 5.2.3.4 PRACTICAL RECOMMENDATIONS

As the porcelain thickness decreases, the strength decreases, therefore it is advisable to construct the porcelain as thick as possible as long as this thickness is below its recommended limit of 2,0 mm. With a desirable metal alloy thickness of 0,2 mm, at least 1,0 mm thickness of porcelain is needed to meet the minimum strength values indicated by the control group.

Thereafter it is advantageous to increase only the porcelain thickness to a maximum of 2,0 mm before the alloy thickness is also increased to gain support for the porcelain. It is vital that the porcelain is of a consistent thickness in order to control excessive shrinkage of porcelain toward the bulkiest porcelain sections. This will result in the need to reach a compromise between maximizing porcelain thickness in all areas and maintaining a relatively even thickness of porcelain coverage due to the change in available space from the margins to the cusp areas (Figure 5.1).

When considering optimum thickness values for the ideal die preparation, there should be 2,0 mm of space available occlusally or incisally; 1,5 mm around the middle third of the crown and at least 1,0 mm at the margins respectively (Figure 5.1). Obviously the most critical area is therefore the marginal area where space availability may be forced below the minimum 1,2 mm requirement. The porcelain in this area is not supported as completely by the metal alloy substructure as in the rest of the crown, and has a tendency to allow tensile stresses to concentrate in it, thereby reducing the strength of the porcelain significantly. If occlusal forces are allowed to concentrate in these areas, due to a loosely fitting crown or a high spot of porcelain in the marginal area, the porcelain may chip away from the margins. As a result the marginal preparation is the most critical factor, followed by the correct control of porcelain shrinkage by the metal ceramist. Condensation techniques during porcelain application are also important considerations to improve strength characteristics of porcelain (Yamamoto 1985:447-481). Proper cementation techniques are expected to improve marginal porcelain stability and strength even further.

The increase in strength is obviously not from the porcelain alone as this is not strong enough on its own, but must be attributed to the combined synergistic effect and the establishment of a successful bond that allows porcelain to be placed into compression.

The contribution of the metal ceramic bond is noted in the way that bonding platinum foil on the fitting surface of a crown increases its strength by up to 83% (Mclean, 1980:172). However, in this study the contribution of porcelain thickness to the overall strength of the restoration was much greater than had been expected. It is therefore recommended that the porcelain thickness be maximized as far as possible to maximize strength and aesthetic characteristics, and that the porcelain thickness be at least 1,0 mm. This value coincides with the 1,0 mm minimum thickness of porcelain that has been recommended by literature (Kersten, 1988:383). Since 1,0 mm thickness is above the critical strength value for porcelain, it is most probable that reducing the porcelain to a minimum of 1,0 mm will produce acceptable results providing that the alloy thickness and design considerations are adequate.

In view of the role of porcelain thickness and its relationship to porcelain strength as shown in the results (Table 4.1), Hypothesis One, i.e. that a critical force value needed to fracture porcelain could be identified for each porcelain thickness, was accepted.

## 5.3 DESIGN CONSIDERATIONS TO MAXIMIZE STRENGTH AND AESTHETIC CHARACTERISTICS OF PORCELAIN IN METAL CERAMIC RESTORATIONS

It was hypothesized that the knowledge of the nature of fracture patterns for porcelain would set the basis for formulating predictability to allow maximizing of strength and aesthetic requirements for metal ceramic restorations.

This hypothesis was accepted, since the nature of porcelain, even due to Griffiths flaws, showed a set pattern of porcelain fracture (Table 4.2). This allowed general recommendations regarding the overall significance between sample groups to be made. These recommendations are based on comparative values of the samples to the control, which set a good acceptable standard for clinical acceptability.

### *5.3.1 CLINICAL ACCEPTABILITY OF STRENGTH VALUES*

Only those sample groups where the lowest fracture value was above or similar to that of the lowest value of the control group could be accepted as having superior or acceptable strength values. These are briefly discussed in order to formulate recommendations for safe use in practice. A comparison of these samples to the lowest value of the noble metal ceramic control group of 28.09 Newtons is also made.

Tables 4.1, 4.2 and 4.3 show that all the samples of Groups B, C, D, F, G, H, I and J would be acceptable commercially, as the lowest breaking values of these base metal alloy samples were all above that of the clinically acceptable noble alloy control group. Groups A and E would not be acceptable, since these two groups had lower strength values than 28,09 Newtons. However Group A had a lowest strength value of 26.75 Newtons which was so close to that of the clinically acceptable control group, that this group should still be acceptable in practice should the design of the metal ceramic restoration be optimal. Reducing the thickness of base metal alloy to 0,1 mm did not optimize strength and aesthetic benefits and as such this formulation cannot be recommended as being of significant benefit to metal ceramic restorations.

Group E showed values as low as 10,44 Newtons, indicating that the porcelain thickness should not be reduced to below 1,0 mm. This indicates that at least 0,2 mm thickness of base metal alloy and 1,0 mm thickness of porcelain is necessary to meet strength and aesthetic requirements of metal ceramic restorations. This also supports a minimum tooth reduction of 1,2 mm.

For the purpose of this study lower strength values were investigated, in order to recommend minimum standards that would still fall above clinically acceptable strength value. Although the physical properties of porcelain did not allow accurate predictions of success rates higher than 91% (Table 4.3), this finding is consistent with Yamamoto's study (1984.5). It is therefore argued that the findings of this study and the resultant recommendations would assist in maximizing strength and aesthetic characteristics of base metal alloy ceramic restorations.

### *5.3.2 PRACTICAL SIGNIFICANCE*

For Sub-problem Three, the results from Sub-problem One, Two and Three were integrated in order to determine which factors would maximize both the strength and aesthetic characteristics of base metal alloy ceramic restorations.

Since the space available for a metal ceramic crown varies considerably from the occlusal to the marginal areas (Figure 5.1), it was of vital importance to integrate Sub-problem One and Two in order to maximize both strength and aesthetic demands for metal ceramic restorations. It is acknowledged that due to the design limitations of this study, all the recommendations that are offered are based on the assumption that thickness variations for the design employed by this study could be applicable to other metal ceramic designs.

The recommendations flowing from the findings in Sub-problem One, i.e. that porcelain coverage be as uniform as possible while porcelain thickness needs to vary from 1,0 mm at the margins to 2,0 mm incisally, are not conflicting. A compromise needs to be reached since both factors contribute to an increase in the strength of porcelain. However, an important finding in this study is that adequate porcelain thickness is the most important factor for optimum strength and aesthetics. Maintaining as even a thickness of porcelain as possible is a secondary factor that needs to be considered. It is the purpose of this discussion under Sub-problem Three to integrate the information gained from the first two sub-problems in order to determine criteria whereby strength and aesthetics may be maximized. This will result in understanding the influences of the metal alloy and porcelain with respect to each other.

#### 5.3.2.1 MAXIMIZING AESTHETIC AND STRENGTH CHARACTERISTICS

Both the alloy thickness and the porcelain thickness play a significant role in increasing the strength of the restoration. However, only the increase in depth of porcelain plays a significant role in improving the aesthetics. If the increase in strength is similar regardless whether the alloy thickness or porcelain thickness is increased, it stands to reason that it is preferable to rather increase the thickness of porcelain.

Since increasing the porcelain thickness is more advantageous in some instances to increasing the alloy thickness, it would seem best to keep the alloy thickness to a minimum at all times while maximizing on the porcelain thickness. Section 5.1 shows that the minimum recommended thickness of base metal alloy is 0,2 mm. As a result, once 0,2 mm alloy thickness has been obtained, it is more beneficial to increase the porcelain thickness thereafter as long as it does not exceed the maximum 2,0 mm.

It was shown that 1,6 mm of porcelain thickness was sufficient to maximize strength characteristics (Table 4.1) and that it was more than sufficient to match a shade. The benefit of increasing the metal to 0,4 mm thereafter was shown in Group J (Table 4.3). Increasing the metal alloy to 0,4 mm also decreased the coefficient of variation value to 3.19% (Table 4.1), thus improving the manufacturing accuracy in reproducibility. This however, relied on the porcelain thickness remaining at the 1,0 mm minimum thickness. When the porcelain thickness was increased to 1,6 mm, the coefficient of variation value increased again to 14.38% even though the metal alloy was also 0,4 mm thick. This shows that although an increase in porcelain thickness increases strength and aesthetic characteristics, it may reduce the consistent results of the reproduction process. This may be due to an increase in the amount of Griffiths flaws and may adversely affect the unexplained percentage of clinical fractures.

For ideal tooth restorations the following factors apply:

1. It is necessary to reduce the metal alloy at the marginal area (Figure 5.1) to 0,2 mm and porcelain to 1,0 mm thickness.
2. At the middle third of the restoration, the alloy thickness should remain 0,2 mm and porcelain thickness should be increased to 1,3 mm.
3. At the cuspal area the metal alloy thickness should be increased to 0,4 mm and the porcelain thickness to 1,6 mm.

If the preparation design does not allow a minimum thickness of 1,0 mm at the margins and 1,2 mm occlusally, a metal collar or metal bite spots should be included in the design.

One of the greatest aesthetic problems is the shadow of a line that shows between the translucent porcelain and the alloy that blocks out the light, especially in anterior crowns. This may further indicate the need for relatively even porcelain coverage supported by the metal alloy to improve aesthetics due to an even depth perception of porcelain. Therefore if there is too much space for porcelain and base metal alloy, the recommended porcelain thickness and even porcelain coverage should be maintained to maximize aesthetics, while the base metal alloy thickness should be increased to support the porcelain.

From this study it is evident that sufficient porcelain depth is the critical factor. If this is not allowed, a metal ceramic restoration cannot be recommended. Although many such restorations are being fabricated, a compromise between strength and aesthetic characteristics is vital, and if this does not happen, such restorations will have limited success regarding maximum strength and aesthetic characteristics.

#### 5.3.2.2 DISTORTION OF THIN BASE METAL ALLOY SECTIONS

In this study it was found that base metal alloy of 0,1 mm distorted the most, with slight alloy distortions of the 0,2 mm alloy samples and no significant distortion of 0,3 or 0,4 mm samples. These findings cannot be ignored. It is therefore argued that, in the light of the marked strength decrease occurring from 0,2 mm to 0,1 mm in the thickness of base metal alloy samples, it would be beneficial for maximum strength and aesthetic characteristics to use a minimum metal alloy thickness of 0,2 mm. Thereafter it is more beneficial to increase only the porcelain thickness since this increases both strength and aesthetic demands while maintaining a relatively even thickness of porcelain coverage. Increasing the metal alloy to 0,3 mm, 0,4 mm or above 0,4 mm where maximum porcelain thickness is allowed will optimise strength characteristics.

The distortion or warping of the alloy resulting in the possibility of a poor fitting restoration, may also result in fractures occurring in the porcelain. This is because porcelain is a brittle material that will fracture readily if it is unsupported, even in the critical strain order of 0.1%. Should the alloy distort as was observed in the 0,1 mm thick alloy samples during working and firing procedures, resulting in increased tensile stresses in the porcelain, it may result in an increased incidence of porcelain fractures.

It is advantageous for porcelain support to have the metal alloy as thick as possible, yet it is for aesthetic reasons that the alloy thickness needs to be reduced. It is, however, also for strength requirements that the porcelain thickness needs to be increased to provide compressive strength within itself.

Since this study was limited with regard to the reasons for the distortion of the alloy and porcelain, the extent to which copings can be reduced to 0,1 mm without distorting and the influence of the observed distortion on strength as a result, cannot be addressed. This is an area where further research is needed. Still, any possible distortion is not desirable, and it has been clearly demonstrated that base metal alloy should not be reduced to 0,1 mm due to the reduction in strength and the increase in alloy distortion.

#### 5.3.2.3 THE ROLE OF BASE METAL ALLOY THICKNESS

The role of the base metal alloy regarding the required thickness is:

1. To provide support for the porcelain.
2. To allow for a metal ceramic bond on which the success of the restoration is reliant.
3. To prevent bending or distortion of the porcelain, thus preventing fracture thereof.
4. To allow for an accurate fit of the substructure, thereby increasing the strength of the porcelain.

Once 0,2 mm alloy thickness has been obtained, most of these requirements are met and the greater benefits gained by rather increasing the porcelain thickness can be realized. This can be related to the requirements of a metal ceramic crown where the alloy needs to be as thin as possible at the margins and middle third of the crown, with maximum porcelain thickness. As a result it is recommended that the base metal alloy be kept to a thickness of 0,2 mm here and porcelain thickness be increased until at least a depth of 1,6 mm, before further alloy thickness increases are made. However, this is very unlikely to happen throughout the design due to space constraints, especially at the marginal areas. The same principles apply to occlusal and incisal areas where an increase in porcelain thickness may result in more compression in porcelain, resulting in increased tension in the porcelain in the marginal areas. Therefore, although aesthetic demands are for slightly thicker porcelain layers, a depth of 1,6 mm porcelain is recommended, especially for the incisal areas. This will strengthen the porcelain not only in that area but in thinner areas as well if porcelain depth is more consistent.

As even a porcelain layer as possible is advantageous and since this study only dealt with even porcelain coverage of samples, large variations in thickness of porcelain for various areas cannot be recommended; but rather variations in the thickness of the metal alloy. Such variations in thickness of alloy may further improve strength characteristics due to a corrugated form resulting from thin and thick areas in the alloy.

Space limitations require that the alloy be as thin as possible; for noble metal alloys this limit is 0,3 mm and for base metal alloys, although it is possible to go to 0,1 mm with success, a 0,2 mm thickness is advocated, otherwise the porcelain depth needs to be increased to such an extent that sufficient space of porcelain must be allowed to ensure success. This depth of space is not always allowed due to conservative tooth preparations possibly resulting from a cautious approach in order to protect the pulp of the tooth in younger teeth, or where teeth are very worn to such an extent that available space for retention of the restoration is limited .

If there is sufficient space for porcelain of approximately 1,3 mm thickness and 0,1 mm of alloy thickness, the restoration is slightly more successful than if the alloy is 0,3 mm with 1,0 mm thickness of porcelain. This indicates that the porcelain has slightly greater benefits for strength and aesthetics as long as the minimum alloy and porcelain thickness is allowed for (Table 4.3).

In support of the studies of both Yamamoto (1985) and Weiss (1983), this study has also indicated recommendations that may result in the success of metal ceramic restorations based on the findings that both porcelain and base metal alloys contribute to the strength of a restoration. The ideal alloy-to-porcelain thickness ratio may lie somewhere between the recommendations made by Yamamoto (1985) and Weiss (1983). This may depend on the availability of space for a specific restoration, and it is hoped that this study and its recommendations may be of value in this regard.

From this study there is a tendency to suggest that 0,2 mm alloy thickness is ideal where space is sufficient for a metal ceramic restoration. Thereafter the additional thickness of porcelain has greater strength and aesthetic advantages.

#### 5.3.2.4 CONNECTOR THICKNESS RECOMMENDATIONS

This study was limited regarding connector thickness recommendations. However, since Weiss (1983) reduced connectors up to 1-2mm, the recommended 2.5mm for anterior and 3.0mm for posterior connectors, depending on the length of the bridge, would be a safe recommendation to follow, since sufficient strength and aesthetics are achievable with these connector dimensions. Moreover, space availability is not generally a problem in these areas if the connectors are designed slightly lingually. The increase in strength of porcelain in the connectors will only be due to adequate thickness of porcelain being allowed to cover the connectors, which may contribute to a reduction of porcelain fracture in this area. However, this is more reliant on design factors than space limitations since insufficient space availability would indicate that a bridge should not be attempted in the first place.

# CHAPTER SIX

## 6.1 CONCLUSIONS

1. In this study the tensile test values did not show any marked difference between strength values of the noble metal alloy control and base metal alloy samples of exactly the same alloy and porcelain thickness (Table 4.3). However, it was established that it is possible to reduce base metal alloy thickness to 0,2 mm successfully as long as sufficient space is available for porcelain to meet aesthetic and strength requirements of at least 1,0 mm porcelain depth. This is due to the superior properties of base metal alloys regarding higher values of modulus of elasticity, as well as their resistance to creep and sag during porcelain firing procedures.

2. A reduction of base metal alloy to 0,1 mm is not advisable due to the marked reduction in strength, even if a larger bulk of porcelain than 1,0 mm is allowed for. This is because it requires more space to meet strength and aesthetic demands than if the alloy is reduced to only 0,2 mm, and if there is so much extra space there is obviously no need to reduce the alloy this much. It is also not ideal because of the possibility of subjecting the base metal alloy to warping during manufacturing procedures.

3. Should there be less than 1,2 mm space for the alloy and porcelain, strength and aesthetic demands are not likely to be achieved and the use of a metal ceramic restoration would be at risk of failure.

4. Predictability of success with the use of porcelain and base metal alloys is not conclusive, as a certain percentage of unexplainable fractures seem inevitable, even though all design criteria have been adhered to.

5. The highest strength values were for samples where the alloy thickness was 0,4 mm and that of porcelain 1,6 mm giving a total thickness of 2,0 mm. The thickest samples were those employed in Group J. However, the standard of deviation for tensile tests was the lowest when 4.0mm of porcelain was supported by 0,1 mm of metal in Group D. The standard of deviation when porcelain was 4,0mm in Group D was more than ten times lower than that of Group J. This raises the question whether consistent manufacturing results can be improved by these alloy to porcelain thickness ratios. Further research may be needed to establish which factors are important for long-term success. However, the need for support of porcelain by the metal alloy is important as a design principle.

6. There are still many areas regarding base metal alloys that are not completely understood, especially regarding coefficient of thermal expansion and the mechanism of porcelain to metal alloy bonding.

7. This study concluded that the reduction of base metal alloy and porcelain thickness may need to vary for every case. Moreover, the data from this study demonstrated that maximizing strength and aesthetic characteristics was possible for each metal ceramic restoration relative to the availability of space for appropriate base metal alloy and porcelain thickness.

## 6.2 RECOMMENDATIONS

1. Further research may establish whether longevity of metal ceramics with reference to the porcelain is better for thicker, stronger sections of porcelain, regardless of whether standard of deviation may be larger. Manufacturing reproducibility may be lower for thinner sections of recommended porcelain thickness. Although thinner porcelain sections are weaker they exhibit a small standard of deviation and possibly more consistent manufacturing results.

2. It is recommended that at least 0,2 mm base metal alloy thickness and 1,0 mm porcelain be obtained, and that the coping not be reduced below these levels due to strength requirements. Besides the strength being below the critical strength value, the alloy may also be prone to warping, causing the strength to decrease radically as compared to 0,2 mm alloy which is not much thicker in real terms. The difference between 0,2 mm and 0,1 mm of base metal alloy thickness would provide no marked decrease to the aesthetics of the porcelain.

3. If there is less than 1,2 mm space for the minimum thickness of 0,2 mm alloy and 1,0 mm porcelain, a metal ceramic restoration is not recommended. It is the researcher's recommendation to rather utilize a restoration of one material only such as a full metal restoration, as the aesthetics would be negatively affected in any case, and the synergistic abilities of the metal ceramic restoration due to the alloy and porcelain combination cannot effectively be utilized.

4. It is recommended that the porcelain be supported by the metal substrate and that porcelain thickness does not exceed 2,0 mm. However, in order to maintain an even coverage, porcelain of 1,6 mm should be supported as a maximum in cuspal areas rather than going to 2,0 mm due to the shape of tooth preparations. Therefore, once 0,2 mm alloy thickness has been achieved, the porcelain thickness should be maximized until 1,6 mm porcelain depth has been obtained, after which the alloy should be thickened proportionately to maintain an even coverage of 1,6 mm of porcelain, thereby maximizing strength and aesthetics.

## 6.3 PRACTICAL SIGNIFICANCE

1. Ensuring sufficient porcelain thickness is just as important for the strength of a metal ceramic restoration as ensuring sufficient alloy thickness. There is a tendency during metal ceramic design to keep the porcelain coverage too thin in order to maintain the tooth restoration within the arch curvature. Slight increases in porcelain thickness may however create a better natural individual tooth effect if utilized correctly. With practice the aesthetics and strength characteristics can be improved by increasing the porcelain thickness slightly in the correct areas.

2. Success of metal ceramic restorations starts from the tooth preparation and alloy substructure design, that can allow for maximizing of strength and aesthetic characteristics.

3. At least 0,2 mm base metal alloy coping thickness is necessary to maximize strength and aesthetic characteristics of restorations for situations where 1,0 mm to 1,6 mm of porcelain is permitted.

4. Reducing copings below 0,2 mm is not recommended for base metal alloys, therefore a general reduction of at least 1,2 mm of tooth structure needs to be prepared to ensure success of base metal ceramic restorations regarding strength and aesthetic characteristics.

5. Manufacturing results of porcelain performance can be improved with specific alloy to porcelain thickness combinations such as 0,4 mm base metal alloy combined with 1,0 mm porcelain. This indicates that using as thick an alloy substructure as possible with only 1,0 mm of porcelain to obtain the minimum depth to match a shade, allowed for the most accurate reproducibility during manufacture, but did not necessarily produce the greatest strength and aesthetic benefits. However, due to a noticeable percentage of unexplained fractures, accurate reproducibility during manufacture may be an important long-term consideration and further research in this field may be beneficial.

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