An in-vitro study of the physical properties of core build-up materials.

A mini thesis submitted in partial fulfilment of the requirements for the degree of Magister Chirurgiae Dentium in Prosthodontics at the Faculty of Dentistry (University of the Western Cape)

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DECLARATION

I hereby declare that the study: "*An in-vitro study of the physical properties of core build-up materials"* is my own work, that has not been submitted before for any degree or examination in any university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Signed:

Winifred Margret Asia June 2017

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I wish to acknowledge the following people for the assistance given to me in this research project.

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Dr D Moodley: My co-supervisor who was always supportive and provided guidance during the course of this study.

DEDICATION

I dedicate this to my lovely husband who always supported me and believed in me (I love you).

To my parents who provided me with what I needed to reach this level of education.

Lastly I dedicate this to all my family and friends for their support, encouragement and patience.

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Abstract

Aim: The aim of this study was to evaluate and compare the physical properties of two core build-up materials (ParaCore and CoreXflow) and compare this to conventional composite material (Filtek Supreme Plus and SDR Flow) used as core build-up material.

Material and Methods:

For the flexural strength 48 specimens were prepared according to ISO 4049:2009 using 2 core build-up materials namely ParaCore and CoreXflow and 2 conventional composites namely Filtek Supreme Plus and SDR Flow. The specimens were divided into 12 specimens per group (n=12). The mean specimen dimensions were 25 mm x 2 mm x 2 mm. The specimens were stored in distilled water in an incubator at 37 °C for 24 hours prior to testing. A universal testing machine, Tinius Olsen H10KT (Horsham, USA) was used to test for flexural strength. Load was applied at a cross-head speed of 0.5 mm/min until fracture. The force applied at the time of fracture, was then recorded in Newtons.

To determine the shear bond strength, a cavity preparation was created in 120 extracted maxillary central incisor teeth. The teeth were randomly divided into 4 groups (n=30). Each group was restored with ParaCore, CoreXflow, Filtek and SDR. The teeth were mounted into PVC pipes with acrylic resin, making use of a surveyor (Dentalfarm, Torino, Italy). Teeth were stored in distilled water in an incubator at 37 °C, 24 hours prior to testing. The teeth were then secured in a jig in order to apply the load at an angle of 45 degrees making use of a universal testing machine. The specimens were subjected to a load at a crosshead speed of 0.5mm/min to the dentine and restorative material interface until fracture. The force applied at the time of fracture, were then recorded in Newtons. A light microscope (Wild Heerbrugg M5, Switzerland), 40 x magnifications, was then used to study the failure patterns of the different core materials. The statistical analysis for the strength of the core material was

performed using statistical programs (SPSS version 21, IBM, USA). The mean values with its standard deviation were calculated for each material. Multiple comparison tests were computed to determine whether statistically significant differences ($p < 0.05$) existed among the core materials.

Results:

Multiple comparisons were performed using the Pairwise comparisons test (Dunn-Sadak) to determine if there were any significant differences in flexural strength of the materials tested. The mean flexural strength (FS) was highest for CoreXflow followed by ParaCore. When flexural strength was analysed there was a significant difference between the materials specifically designed as core build-up materials (CoreXflow and ParaCore) and the conventional composite materials being advocated as core build-up materials (Filtek Supreme XTE and SDR flow) ($p<0.05$). No significant difference in flexural strength was found between the conventional composites ($p>0.05$). No significant difference was also found between the core materials (CoreXflow and ParaCore) ($p>0.05$). A significant difference was found between Filtek and ParaCore and Filtek and CoreXflow ($p<0.05$). A significant difference was also found between SDR and ParaCore and SDR and CoreXflow ($p<0.05$). The mean Shear Bond Strength (SBS) was highest for SDR flow followed by ParaCore. No significant difference in shear bond strength were found between the materials tested ($p>0.05$).

Conclusion:

In the present study the resin composite materials specifically designed for core build-up materials showed higher flexural strength compared to the conventional restorative composites used as core materials. A significant difference was found in the flexural strength of these materials. No significant difference however was found when the shear bond strength of these materials were analysed. Various conventional composite restorative materials are being indicated as core materials however flexural strength might not be adequate for use as core-build up materials.

Key words

Flexural strength

Compressive strength

Shear bond strength

Core build-up material

Composite resin

CHAPTER 1

Literature Review

1.1 Introduction

Excessive loss of the coronal portion of a tooth creates a challenge to clinicians, due to the lack of sufficient tooth structure to retain a restoration. Core build-up materials are generally advocated to replace the bulk of the tooth, consequently providing the necessary retention, resistance and support for the definitive restoration (Combe, *et al.*, 1999). An ideal core build-up material must present excellent physical/mechanical properties in order to resist the stresses that may be produced during function, providing equitable stress distributions of forces and reducing the probability of tensile and compressive failures (Passos, *et al.*, 2013).

Traditionally dental amalgam, glass ionomer and resin composites were employed as standard core build-up materials. Several studies have compared the mechanical and physical properties of these materials with variable results (Combe, *et al.*, 1999; Petronijevic, *et al.*, 2012; Markovic, *et al.*, 2011). Newer formulations of resin composites have also been introduced over the years. The mechanical properties of these composites are greatly enhanced by alterations in their filler size and distribution of the fillers (Finan, *et al.*, 2013).

The flexural strength is only one of the criteria for the selection of core materials, and is an important property to resist deformation and fracture of a restoration during functional forces. Compressive and tensile strengths of core material are thought to be important because the core usually replace a large bulk of tooth structure and must resist multi-directional masticatory forces for many years (Combe, *et al.*, 1999). The core material should have compressive strength to resist intraoral forces and flexural strength to prevent core dislodgement during function.

The shear bond strength of a core material is a crucial property that will determine the ultimate suitability of a material to be advocated clinically. The adhesion of the material to the dentine surface must be adequate in order to withstand any functional forces that will dislodge the restoration. There is a relationship between the shear bond strength and the composite flexural strength and between bond strength and flexural modulus. Stress concentration at the bonded interface decreases as the composite's elastic modulus is increased (Thomsen & Peutzfeldt, 2007).

1.2. Definition of terms

- **Core build-up materials:** materials that are used for restoring badly broken down vital or non-vital teeth that are to be used as abutments under subsequent restorations trying to stabilize its weakened part, providing a foundation for the tooth that allows the clinician to create a favourable retention and resistance form for the overlying prosthesis (Shilingburg, *et al.*, 1997).
- **Resin filled composite:** These materials are all composed of a polymeric matrix, typically a dimethacrylate, reinforcing fillers, typically made from radio-opaque glass, a silane coupling agent for binding the filler to the matrix, and chemicals that promote or modulate the polymerization reaction (Ferracane, 2011). Resin filled composites are the result of inter-atomic or molecular interaction between two or more components, the overall properties of which are superior to those of the individual components alone (Dogon, 1990).

- **Flowable composite:** a hybrid composite that is produced with a lower viscosity by reducing the filler content of the mixture, or by adding other modifying agents, such as surfactants, which enhance the fluidity while avoiding a large reduction in filler content that would significantly reduce mechanical properties and increase shrinkage (Bayne, *et al.*, 1998).
- **Packable composite:** a hybrid resin composite designed for use in posterior area, where a stiffer consistency facilitates condensation in posterior teeth (Anusavice, *et al.*, 2013). Packable composites achieve their thicker consistency through modification of the filler size distributions or through the addition of other types of particles, such as fibers, but generally not by increasing overall filler level (Choi, *et al.*, 2000).
- **Bulk-fill composite:** Bulk-fill composite have been introduced by manufacturers to reduce polymerization shrinkage stresses, by modifying monomers to create monomers with lower viscosity so that it can be cured in bulk at 4mm (Garcia, *et al.*, 2014).
- **Flexural strength:** Fracture toughness is an intrinsic property of a material and is a measure of the energy required to propagate a crack from an existing defect (Bonilla, *et al.*, 2003).
- **Compressive strength:** The internal resistance of the material to breaking under compression (Anusavice, *et al.*, 2013).
- **Shear Bond strength:** The process of mastication is basically related to shearing phenomenon and the true nature of the adhesive strength of materials at the tooth and restoration interface is described by the shear bond strength (SBS) (Nujella, *et al.*, 2012).

1.3. Core Materials

A foundation restoration or core is used to build a badly broken down tooth to restore the bulk of the coronal portion of the tooth to an ideal anatomic form before the full coverage crown is placed. It should provide the patient with a long-lasting restoration with adequate function (Agrawal & Mala, 2014).

Core materials are classified as either cast cores or plastic core materials. The cast cores include cores that are made of metal, ceramics or zirconia. The plastic core materials include, amalgam, resin composites, glass ionomer, resin modified glass ionomers and dual cure fibre reinforced cores (Anusavice, *et al.*, 2013).

An ideal core build-up material should have physical properties similar to those of tooth structure, as a restored tooth tends to transfer stress differently than an intact tooth (Jain, *et al.*, 2015). A restored tooth, allows complex stress distribution pattern along the tooth and restoration interface, producing compression, tension or shear stress. The process of mastication is basically related to shearing phenomenon and the true nature of the adhesive strength of materials at the tooth and restoration interface is described by the shear bond strength (SBS) (Nujella, *et al.*, 2012). Compressive and tensile strengths of core materials are thought to be important because cores usually replace a large bulk of tooth structure and must resist multidirectional masticatory forces for many years (Anusavice, *et al.*, 2013). Flexural strength of core materials is considered to be sensitive to surface imperfections such as cracks, voids, and related flaws, which can influence the fracture strength of brittle materials. Several dental materials have been used for core build-up procedures (Saygili & Sahmali, 2002).

A core material could either be metallic, resinous or ceramic, being directly or indirectly constructed. Gold alloys and ceramics, which were placed as indirect core materials, and the directly placed amalgam, were the most common core materials used until relatively recently. Within the past few years, directly placed tooth-colored restorative materials were introduced for use as core build-ups, as opposed to metallic dental amalgam; namely; resin composites and glass-ionomers. These reduced clinical time by providing the possibility of core build-up and tooth preparation to be done in the same appointment (Wassell, *et al*., 2002).

Cores could be retained in place through several methods, including cavity modifications, as well as application of resin or cement bonding agents. Pins could also be used, either single or in combination (Wassell, *et al*., 2002). In case of endodontically treated teeth, cores are either in cast forms as one unit with the post, or are built-up on ready-made posts seated in the root-canal (Shilingburg, *et al*., 1997).

Amalgam, composite resin, and glass-ionomer materials have typically been used as core build-up materials (Passos, *et al*., 2013). A study by Combe and colleagues in 1999 tested the mechanical properties of direct core materials, namely amalgam, glass ionomer, a visible light cured resin composite and 2 chemically cured resin composites. Within one hour of testing, amalgam demonstrated a lower compressive and tensile strength compared to resin composite. The compressive and tensile strength of amalgam however increased significantly after 24 hours. Amalgam and resin composite also had a compatible elastic modulus after 24 hours, in contrast to glass ionomer, which have revealed to be an inferior material in all parameters (compressive and tensile strength; elastic and flexural modulus) studied (Combe, *et al*., 1999).

1.3.1. Amalgam as core material

One important disadvantage of amalgam restorations is lack of adhesion to tooth structure, which may compromise marginal sealing. This lack of adhesion to the tooth causes colour changes at the interface of the materials, pulpal irritation, postoperative sensitivity, and ultimately results in secondary caries. Conventional amalgam alloys display a marked decrease in microleakage as the restoration ages. This seal is due to the accumulation of corrosion products along the interface, which block the ingress of injurious agents (Gallato, *et al*., 2005).

The gamma-2 (y-2) phase is important to the formation of the seal. High-copper amalgam (admixed and spherical type) restorations are usually free of the y-2 phase, which is the weakest and most corrosive phase of the amalgam restoration. As a result, less corrosive products are created with high-copper amalgam, and the corrosion process is slower than for conventional amalgams. Leakage is reduced with alloys of a high copper content (Agrawal & Mala, 2014). Controversial results regarding the performance of different amalgam alloys were reported. Meiers and Turner (1998) found no differences in the short- and long-term microleakage for a spheroidal alloy while the admixed alloy showed a higher microleakage after 1-year. However, Ziskind et al. (2003) showed significant differences for these 2 amalgam alloys for both short- and long-term storage. The 3-way interaction between time, restoration and adhesive use was significant (p= .04 and p= .015 for the cervical and occlusal margins respectively). After long-term storage, dye penetration values decreased in both groups and reached a lower level compared to short-term storage.

Development and advances in non-gamma-2 amalgams and the new concepts of bonding dental amalgam to tooth structure have helped to ensure that amalgam remains one of the materials widely used for core build up procedures in posterior teeth. However, this material has disadvantages like poor colour, low-initial strength, lack of inherent bond to tooth structure, and high coefficient of thermal diffusibility (Agrawal & Mala, 2014). Although amalgam is the stronger core material, it has a slower setting time when compared to resin composites and the material's mercury content is a concern to clinicians and patients.

1.3.2. Glass Ionomers as Core Material

Glass ionomers have the advantage of fluoride release, which help to preserve intact dentine. What differentiates glass ionomer material from other restoratives is its chemistry, which allows them to be self-adhesive to enamel and dentin and provide for caries-protective fluoride release at the margins of restorations, as well as their ability to have the fluoride within their chemical matrix recharged by outside exposure to other fluoride-containing materials. Other unique features include their moisture tolerance, allowing glass ionomer to be used for a wide variety of clinical applications. The preservation of intact dentine greatly enhances the material's shear bond strength. The disadvantages of conventional glass ionomer material are brittleness, lack of strength, toughness and poor resistance to wear. Resin-modified glass ionomer restorative materials and compomer or polyacid–modified composite resin were introduced in 1990s which is a single component material with the advantages of both composites and glass ionomers (Nujella, *et al.*, 2012).

Resin-modified glass-ionomer is the modification of glass-ionomer cement by the incorporation of polymerizable functional groups. These products are hybrids between conventional glass-ionomers and chemically- or light-cured resin restorations, (McCabe, 1998) typically consisting of a powder similar to that of glass-ionomers, a chemically- or light-curable monomer in the liquid, such as hydroxyethylmethacrylate (HEMA), an ion-leachable glass, and water (Craig & Powers, 2002).

As some of the water in resin-modified glass-ionomer system has been replaced by HEMA, the initial setting of these materials is due to the free radical addition polymerization of HEMA. Subsequently, the acid-base reaction typical of conventional glass-ionomer takes place, serving to harden and strengthen the already created polymer matrix, allowing a considerable working time, with ease of manipulation and maintained fluoride-release. Chemical bonding to tooth structure without a bonding agent is maintained. Finally, a metal poly-acrylate salt matrix as well as a polymer matrix is formed (Van Noort, 2002).

Depending on the formulation of the material, and Powder/Liquid ratios, resin-modified glass-ionomers may be used as liners, fissure sealants, bases, core build-ups and restoratives (Anusavice, *et al.*, 2013). These hybrid ionomers set rapidly, after chemical or light initiation, allowing for an immediate finishing of the restoration with better mechanical properties (Anusavice, *et al.*, 2013). Also, improved resistance to desiccation and acid attack is obvious, compared to conventional glass-ionomer cements. The coefficient of thermal expansion and contraction is close to ideal, minimizing the microleakage typical of conventional glass-ionomers (Nomoto, *et al*., 2006).

However, their greater degree of shrinkage upon polymerization compared to conventional glass-ionomers, (Anusavice, *et al.*, 2013) their lower rigidity compared to that of composites, and a strength being lower than that of the tooth structure, hybrid ionomers should only be used as luting agents (Christensen, 2000).

Resin-modified glass-ionomers also lacked translucency. Additionally, due to the presence of the hydrophilic HEMA in the formulation, resin modified glass-ionomers absorb water easily, with accompanying degradation (Kanchanavasita, *et al*., 1998). Also, a retardation of the acid-base reaction and increased microleakage were noticed, due to the reduced carboxylic acid and water quantity in the liquid (Van Noort, 2002).

Resin modified glass ionomer have shown to have lower compressive and flexural strength when compared to composite, amalgam and 2 composite resins specifically designed as core materials. The authors concluded that resin modified glass ionomer materials cannot be considered to be particularly suitable as material for large core build-up procedures in posterior teeth (Combe, *et al.*, 1999). The inferior mechanical properties of resin modified glass ionomer compared to composite and amalgam was also shown in another study (Markovic, *et al.*, 2011). The authors stated that that the highest overall strength of restored incisors with intact dentin, when 50 per cent of the coronal part of the tooth is missing, was achieved by using composite resin and dental amalgam as a transitional restoration and as a core build-up material (Markovic, *et al.*, 2011).

1.3.3. Composite resins as core material

Composite resins are overall easier to manipulate, especially with the introduction of the new flowable composite types, which are applied to the tooth surface by using a syringe (Wassell, *et al.*, 2002; Land & Rosenstiel, 2006). The major disadvantage of composite resins and glass ionomers is that the materials undergo polymerization shrinkage, resulting increased stresses, which ultimately affects the materials shear bond strength, volumetric stability and its mechanical properties (Oliva & Lowe, 1987). Glass ionomers however, displays greater polymerization shrinkage when compared to composite resin (Chutinan, *et al.*, 2004).

1.4. Composite Resins

1.4.1. History of Composites

Composite resins have been introduced into the field of conservative dentistry to minimise the drawbacks of the acrylic resins that replaced silicate cements in the 1940s (Garcia, *et al.*, 2006). Unfortunately, these acrylic resins had relatively poor wear resistance and shrink severely during curing, which cause them to pull away from the cavity wall, thereby producing crevices that facilitated leakage (Anusavice, *et al.,* 2013). In 1955, Buonocore used orthophosphoric acid to improve the adhesion of acrylic resins to the surface of the enamel. In 1962 Bowen developed the Bis-GMA monomer in an attempt to improve the physical properties of acrylic resins, as their monomers only allowed linear chain polymers to be formed (Garcia, *et al.*, 2006). These early, chemically cured composites required the base paste to be mixed with the catalyst, leading to problems with the proportions, mixing process and colour stability. From 1970, composite materials have polymerised by electromagnetic radiation appeared, doing away with mixing and its drawbacks (Garcia, *et al.*, 2006).

At the beginning, these were ultra-violet (UV) activated, to be replaced by visible light-cured (VLC) types, in 1976 (Emami, *et al*., 2003). Dual-cured resins, formed of two light-curable pastes were then introduced, with a combination of both chemically and visible light-curing components to overcome the problems of limited curing depths (Anusavice, *et al.,* 2013). To ensure complete polymerization of composites, and to reduce the inherently occurring polymerization shrinkage, they are to be incrementally placed, except for specifically light-activated core composites, offering depths of cure up to 8 mm, or indirectly constructed inlays (Craig & Powers, 2002).

Composite core materials are often two-paste chemically-cured systems, designed for bulk placement, as well as light-cured and dual-cured products, usually having a contrasting colour to the tooth structure (Anusavice, *et al.,* 2013). For tooth-colored restorative materials being placed directly into the cavity, they also show chemical bonding to the tooth structure by the use of bonding agents under sufficient moisture control. Additionally the rapid command set of the light cured material allows immediate tooth preparation, therefore saving time

(Walmsley, *et al.*, 2002). Due to their high mechanical properties, including tensile and flexure strengths, their acceptance as a core build-up restorative material has increased tremendously (Markovic, *et al.*, 2011). Unfortunately, these materials are not easy to handle, displaying technique sensitivity, due to their incremental placement technique, as well as inadequate degree of conversion (DC) and inherent polymerization shrinkage, with a resulting breakdown at the interface and consequent gap formation with microleakage (Manhart, *et al.*, 2000).

The composition of resin-based dental composites has evolved significantly since the materials were first introduced to dentistry more than 50 years ago (Figure 1). Until recently, the most important changes have involved the reinforcing filler, which has been purposely reduced in size to produce materials that are more easily and effectively polished and demonstrate greater wear resistance. The latter was especially necessary for materials used in posterior applications, but the former has been important for restorations in all areas of the mouth (Ferracane, 2011).

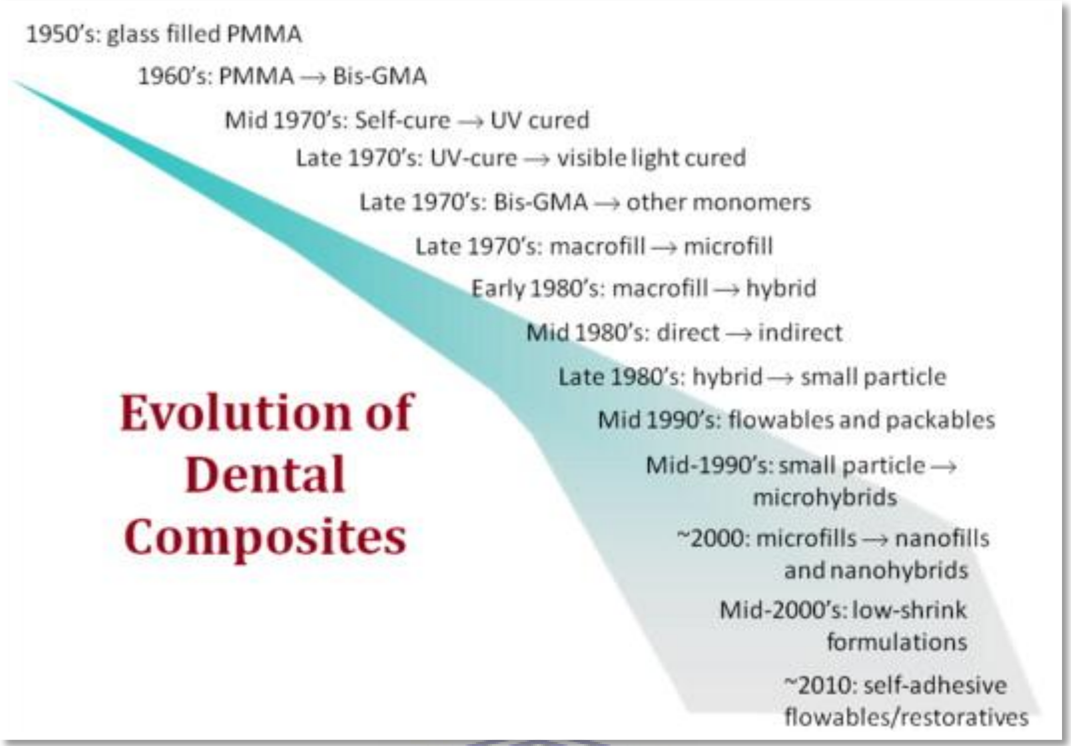


Figure 1: A perspective on the evolution of dental composites (Ferracane; 2011)

Current changes are more focused on the polymeric matrix of the material, principally to develop systems with reduced polymerization shrinkage, and perhaps more importantly, reduced polymerization shrinkage stress, and to make them self-adhesive to tooth structure (Chen; 2010).

1.4.2. Composition of composites

Dental composites are composed of three chemically-different materials: the organic matrix or organic phase; the inorganic matrix, filler or disperse phase; and an organosilane or coupling agent to bond the filler to the organic resin. This agent is a molecule with silane groups at one end and methacrylate groups at the other (Garcia, *et al.*, 2006). The physical, mechanical and aesthetic properties as well as the clinical behaviour of composites depend on their structure (Ferracane, *et al.*, 2014).

Resin Matrix

The resin matrix in most composites is based on a blend of aromatic and/or aliphatic dimethacrylate monomers (Anusavice, *et al.*, 2013). The predominant base monomer used in commercial dental composites has been Bis-GMA, which due to its high viscosity is mixed with other dimethacrylates, such as TEGDMA, UDMA or other monomers (Ferracane, 2011).

TEGDMA, which is less viscous and has excellent copolymerization characteristics, is frequently used as the diluent monomer for UDMA and Bis-GMA-based composites to provide a fluid resin that can be maximally filled with inorganic particles. TEGDMA increases vinyl double-bond conversion (Chen, 2010). Since UDMA and Bis-GMA have higher molecular weights and fewer double bonds per unit of weight, they generally have less shrinkage than TEGDMA. Therefore, TEGDMA has been replaced by UDMA and Bis-GMA in several products to reduce shrinkage, aging, and the negative effects of environmental factors such as moisture, acid, and temperature changes (Yap, *et al.*, 2000).

The resin matrix also contains photo-initiators like camphoroquinone, which is activated by using blue light of specific wavelength about 470nm to release free radicals in order to cure the composite. Pigments as well as stabilizers are also found within the organic matrix (Anusavice, *et al.*, 2013).

The filler system

The dispersed phase of composite resins is made up of an inorganic filler material. The filler material is added to the organic matrix to increase the physical and mechanical properties of the organic matrix. The filler reduces the thermal expansion coefficient and overall curing shrinkage, provides radio-opacity, improves handling and improves the aesthetic results

(Garcia, *et al*., 2006). The size of the filler particles incorporated in the resin matrix of commercial dental composites has continuously decreased over the years from the traditional to the nano-composite materials.

The resin composites used commonly these days contain 50 to 86 % by weight and 35-71 % by volume of filler particle. The filler particles used have a big difference in their chemical composition, morphology and dimensions. The main filler is silicon dioxide boron silicates and lithium aluminum silicates (Ravi, *et al*., 2013).

Coupling agent

The most commonly used coupling agent is an organosilane such as gamma methacryloxy propyl trimethoxysilane (Ravi, *et al*., 2013). Coupling agents help transmit the stresses from the matrix to the filler particles (Anusavice, *et al*., 2013).

The formation of a strong covalent bond between inorganic fillers and the organic matrix is essential for obtaining good mechanical properties in dental composites. Bonding of these two phases is achieved by coating the fillers with a silane coupling agent that has functional groups to link the filler and the matrix chemically. A typical coupling agent is 3-methacryloxypropyltrimethoxysilane (MPTS). One end of the molecule can be bonded to the hydroxyl groups of silica particles, and the other end is capable of copolymerizing into the polymer matrix (Chen; 2010).

1.4.3. Classification of composites

Lutz and Phillips in 1983 classified composite resins into macro filler composites (particles from 0.1 to 100 µm) micro filler composites (0.04 to0.4µm particles) and hybrid composites (fillers of different sizes) (Table1). This popular classification is still valid (Garcia, *et al*., 2006).

Table 1: Classification of resin based composites (Lutz & Phillips; 1983)

Filler	Composite	Particle size
Macrofiller (ground silica)	Macrofilled composite	1-50 µm
	Hybrid composite	1-20 µm glass 0.04 µm silica
Microfiller (pyogenic silica)	Hybrid midifilled composite	0.1-10 µm glass 0.04 µm silica
	Homogenous microfilled composite	0.04 µm silica
	Heterogeneous microfilled composite	0.04 µm silica Pre-polymersied resin particles containing 0.04 µm silica
Microfiller-based complexes	Heterogeneous microfilled composite	0.1-2 µm glass 0.04 µm silica

Willems et al. (1992) proposed a classification system based on the volume fraction of filler and filler size, this system distinguishes between micro-fine composite, densified composite, traditional composite, miscellaneous composite and fibre-reinforced composite (Table 2). The densified composite were then further subdivided into mid-way (<60 volume %) and compact filled composites (>60 volume %). There is also a sub classification of ultrafine (<3µm) and fine (>3 µm) with each category.

Table 2: Classification of composites (Willems et al., 1992)

Composite type	Filler
Densified composites -Midway-filled Ultrafine Fine -Compact-filled >60% by volume Ultrafine Fine	 < 60% by volume Particles < 3 µm Particles > 3 µm > 60% by volume Particles < 3 µm Particles > 3 µm
Micro-fine composites - Homogeneous - Heterogeneous	Average particle size = 0,04 µm
Miscellaneous composites	Blends of densified and micro-fine composites
Traditional composites	Equivalent to what are termed macro-fill composites in other classifications
Fiber-reinforced composites	Industrial-use composites

However, Zimmerli et al. (2010) stated that this classification does not do justice to all the modern composites which are in use today as most of them are nano-composites. So they classified the composite according to the matrix components (Table 3). Recently, nano composites have been innovated, which contains nano particles (25nm) and nano aggregates (75 nm) (Garcia, *et al*., 2006). As a result of the small size of the particles nano composites can achieve a better finishing, sufficient mechanical properties and decrease polymerization shrinkage (Garcia, *et al*., 2006).

Table 3: Classification of composite according to matrix component (Zimmerli et al., 2010)

Matrix	Chemical system	Group
Conventional matrix	Pure Methacrylate	Hybrid composite Nano composite
Inorganic matrix	Inorganic Polycondensate	Ormocers
Acid modified methacrylate	Polar group	Compomers
Ring opening epoxide	Cationic polymerization	Silorane

Improvements carried out since their introduction were mainly based on the development of new monomers, while for fillers, the developments concentrated on filler loading, particle size, silanization and on developing new filler particles (Chung, *et al*., 2002). According to the type, size, shape, and distribution of its fillers, dental composites were classified into traditional macrofilled composites with larger glass filler particles, microfilled resins introduced in the late 1970s containing colloidal silica particles ranging between 0.01-0.05 µm., followed by microfine particles (0.04-0.2 µm), fine particles (0.4-3 µm), and finally microhybrid blends of fine particles and some microfine particles (Craig & Powers, 2002). A simpler classification system was proposed by Bayne, Heymann and Swift (1994) based on the size of the largest fillers, in which dental composites are classified into microfill (0.01-0.1 µm), minifill (0.1-1 µm) and midifills (1-10 µm).

There are many proposed systems for the classification of resin filled dental composite materials. The most commonly used classification system is based on the size of the filler particles. The following broad system (microfilled, hybrid, packable) was used by Puckett et al. (2007). Additionally, the flowable, nanofilled, and microhybrid were addressed as sub-classification (Puckett, *et al.*, 2007).

Composite resins are classified according to their consistency and filler content. Filler size and distribution are thought to be directly related to the mechanical properties of the different types of composites. Flowable composites have a lower viscosity compared to their more packable counterparts. The material's fluidity is the result of its reduced filler content. These materials are more resistant to wear, easier to polish and are stronger due to the modifications in their filler size distribution (Ilie & Hickel, 2011a). The reduce filler content of flowable composites have some researchers concerned for their use as core build up material, although the reduce filler content greatly reduce the polymerization shrinkage of the material, it might influence its mechanical properties.

1.4.4. Current Composite Materials

The different types of composite materials are distinguished by their consistency. The universal restorative material capable of being placed with a syringe or instrument may have a variety of consistencies depending upon its formulation. These materials are distinguished from the flowable composites, designed to be dispensed from very fine bore syringes into tight spaces for enhanced adaptation, and from the packable composites, designed to provide significant resistance to an amalgam condenser or other instrument in order to avoid slumping and to enhance the formation of tight interproximal contacts (Anusavice, *et al.*, 2013).

Flowable composites are typically produced with a lower viscosity by reducing the filler content of the mixture, or by adding other modifying agents, such as surfactants, which enhance the fluidity while avoiding a large reduction in filler content that would significantly reduce mechanical properties and increase shrinkage (Bayne, *et al.*, 1998). Packable composites achieve their thicker consistency through modification of the filler size distributions or through the addition of other types of particles, such as fibers, but generally not by increasing overall filler level (Choi, *et al.*, 2000).

Within each type of composite, the materials are further distinguished by the characteristics of their reinforcing fillers, and in particular their size (Figure 2).

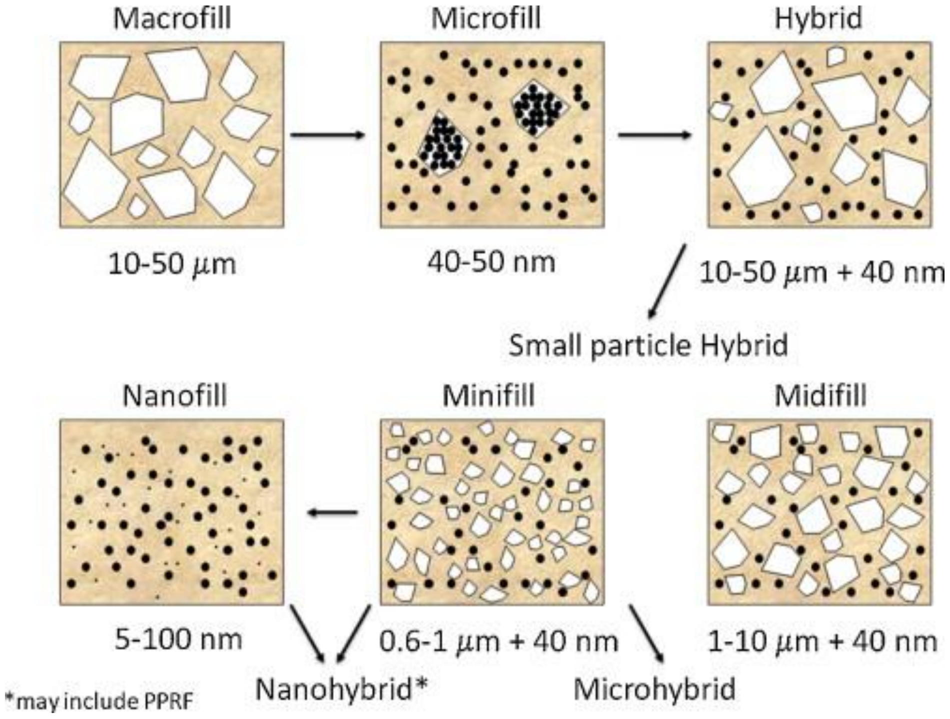


Figure 2: Chronological development of the state of the art of dental composite formulations based on filler modifications (Ferracane, 2011)

Conventional dental composites had average particle sizes that far exceeded 1μm. These “macrofill” materials were very strong, but difficult to polish and impossible to retain surface smoothness. To address the important issue of long-term esthetics, manufacturers began to formulate “microfill” composites. In truth, these materials were truly nano-composites, as the average size of the amorphous spherical silica reinforcing particles was approximately 40nm (Bayne, *et al.*, 1994). The filler level in these materials was low, but could be increased by incorporating highly filled, pre-polymerized resin fillers (PPRF) within the matrix to which additional “microfill” particles were added (Chen; 2010).

The “microfill composites were polishable but generally weak due to their relatively low filler content, and a compromise was needed to produce adequate strength with enhanced polishability and esthetics. Therefore, the particle size of the conventional composites was reduced through further grinding to produce what was ultimately called “small particle hybrid” composites. These were further distinguished as “midifills,” with average particle sizes slightly greater than 1µm but also containing a portion of the 40 nm-sized fumed silica “microfillers.” Further refinements in the particle size through enhanced milling and grinding techniques resulted in composites with particles that were sub-micron, typically averaging about 0.4–1.0µm, which initially were called “minifills” and ultimately came to be referred to as “microhybrids.” These materials are generally considered to be universal composites as they can be used for most anterior and posterior applications based on their combination of strength and polish ability (El-Safty, *et al*., 2012).

The most recent innovation has been the development of the “nanofill” composites, containing only nanoscale particles. Most manufacturers have modified the formulations of their microhybrids to include more nanoparticles, and possibly pre-polymerized resin fillers, similar to those found in the microfill composites, and have named this group “nanohybrids.” In general, it is difficult to distinguish nanohybrids from microhybrids. Their properties, such as flexure strength and modulus, tend to be similar, with the nanohybrids as a group being in the lower range of the microhybrids, and both being greater than microfills (Ilie & Hickel, 2009a)

While some have shown evidence for reduced stability during water storage for nano-hybrid or nano-fill composites vs. microhybrids (Ilie & Hickel, 2009b) others have shown an opposite trend (Curtis, *et al.*, 2009). Regarding clinical evaluations, two recent studies over 2 and 4 years, respectively, showed similar excellent results in class II cavities for a nanofill vs. microhybrid (Ernst, *et al.*, 2006) and nanohybrid vs. a microhybrid, with slight evidence for better marginal integrity for the micro-hybrid in the latter study (Kramer, *et al.*, 2009).

Flowable Composites

Flowable composites are low viscosity resin composites obtained from formulations with 20–25% lower filler loading than conventional composites (Bayne, *et al.*, 1998). The development of flowable composites appeared in the 1990s as an important advancement in restorative dental materials. First-generation flowable composites were used only as liners due to their low elastic modulus. The lower viscosity of flowable composites makes their placement by injection syringes possible. The second-generation flowable composites; developed since 2000 promise increased mechanical properties and are proposed for use in bulk restorations (Perdigao, et al., 2004).

Flowable composites are typically produced with a lower viscosity by reducing the filler content of the mixture, or by adding other modifying agents, such as surfactants, which enhance the fluidity while avoiding a large reduction in filler content that would significantly reduce mechanical properties and increase shrinkage (Ferracane, 2011). Loguercio et al. (2005) and Celik et al. (2007) reported no improved clinical performance of flowable composites when used in non-carious lesions whether used alone or as a liner. Furthermore, Ozel et al. (2008) and Han et al. (2009) did not recommend their application in critical stress areas. A common clinical technique for flowable composites to be used as a liner, is to be in conjunction with the high modulus and high viscous packable composites, but the effect of possible restoration flexure when it is supported by low modulus flowable, and the higher than expected polymerisation shrinkage of flowable are not known (Bayne, *et al.*, 1998).

Their main advantages are: high wettability of the tooth surface, ensuring penetration into every irregularity; ability to form layers of minimum thickness, so improving or eliminating air inclusion or entrapment; high flexibility, so less likely to be displaced in stress concentration areas; radio-opaqueness and availability in different colours. The drawbacks are: high curing shrinkage, due to lower filler load, and weaker mechanical properties (Garcia, *et al.*, 2014).

Bulk-Fill Composites

Bulk-fill resin composites, has been introduced in the past few years. They allow for up to 4- or 5-mm thick increments to be cured in one step, thus skipping the time-consuming layering process. These materials are thought to have a better adaption to the cavity walls and will have adequate polymerization (Ilie, *et al.*, 2013). This new and innovate technology is based on changes in monomer chemistry. Manufacturers introduced this new technology by modifying the Bowen monomer to create monomers with lower viscosity (Czasch & Ilie, 2013). The outcomes of these changes in monomer and composite organic matrix have been shown to reduce polymerization shrinkage stresses by over 70% (Ilie & Hickel, 2011b).

Polymerization shrinkage is related to the organic and inorganic content of the composite resins. Flowable composites generally contain more organic matrix in order to gain increased flow. Thus, they have greater shrinkage compared to hybrid composites, which have less organic matrix (Correa, *et al.*, 2010). As a result of the increased resin matrix, flowable composites reduce internal stresses during polymerization shrinkage due to their lower Young’s modulus compared to regular packable composites (Estafan & Agosta, 2003).

In a study by El-Safty et al. (2012) comparing bulk-fill composites, conventional composites and flowable composites, conventional composites had higher surface hardness and modulus of elasticity while the properties of bulk-fill composites was between the conventional and flowable composites. In a recent study, (Leprince, *et al.*, 2014) the bulk fill composites exhibited lower mechanical properties compared with the conventional composites.

Recently, there have been more bulk-fill composites introduced to the market (Christensen, 2012). Bulk-fill composites are new composite materials aimed to decrease the time taken to place the composite in the cavity by eliminating incremental curing. They are also intended to minimize the shrinkage and the resulting stress by using the same exposure time and light intensity used for the regular composites (Finan, *et al*., 2013). This is made possible by either a reduction in the filler content, altering the filler matrix composition to improve the translucency of the material or by changing the photo-initiator system (Ferracane, *et al.*, 2014).

There are several disadvantages associated with the layering technique in the conventional composite such as, bonding failure between the layers, contamination between composite layers, limitation to access in the small cavities leads to difficulty in placement, time consuming including placement of the composite in increments and curing it (Alrahlah, *et al*., 2014). Bulk-fill composites have been introduced to overcome these disadvantages. When compared with conventional composite filled in an oblique incremental layering technique, bulk-fill composites have shown reduced cuspal deflection. Also, in the evaluation of the marginal integrity bulk-fill composite performed well (Alrahlah, *et al.*, 2014).

Bulk-fill composites are recommended for use in Class I, II, and VI restorations. They are mainly composed of light activated, dimethacrylate resins with a higher percentage of irregular (mixture of irregular particles and rods) or porous fillers (Fortin and Vargas, 2000).

Filler loading in these composite resins varies from 60% to 80% by volume (Fortin and Vargas, 2000). The percentages of filler in the bulk-fill composites are high (Garcia, *et al.*, 2006). Christensen, (2012) reported the advantages of bulk-fill composites including fewer voids may be present as the composite is placed into the cavity as one piece, time saving since there is no need to place the composite in increments.

Using the inter-locking particle technology is a main advantage for the bulk-fill composites where mixtures of different-sized filler particles are used. When these particles are packed together the larger particles mechanically interlock with the small particles (El-Nawawy, *et al.*, 2012). However, there are disadvantages for the bulk-fill; the shrinkage stress might be more when bulk-fill composites are used. The polymerization of these composites might be incomplete when the cavity is deep, making adequate contact areas more challenging unless adequate matrices are used (Christensen, 2012).

Packable Composites

Packable composites achieve their thicker consistency through modification of the filler size distributions or through the addition of other types of particles, such as fibers, but generally not by increasing overall filler level (Ferracane, 2011)**.** These composites were introduced to the market as amalgam substitutes.

The advantages are: condensability (like silver amalgam), greater ease in achieving a good contact point and better reproduction of occlusal anatomy. Their physical and mechanical behaviour is similar to that of silver amalgam and better than that of hybrid composites (Puckett, *et al.*, 2007). Their main disadvantages are difficulties in adaptation between one composite layer and another, difficult handling and poor aesthetics in anterior teeth. Their main indication is Class II cavity restoration where they can achieve a better contact point due to the use of the condensation technique (Garcia, *et al.*, 2006).

Packable composites are a class of highly filled composite resin with a filler distribution which resulted in a different consistency compared to the hybrid composites. Packable composites are characterised with more viscosity and less stickiness compared to conventional composites. For this reason they claimed to be suitable to be placed in stress bearing areas as an amalgam alternatives and their application is similar to amalgam (Leinfelder, *et al.*, 1999).

The first few packable composites were introduced in early 1980s with altered filler characteristics such as filler size, shape, level or microfiller content. Unfortunately, porosity and insufficient wetting of particles by resin resulted from increasing the amount of filler particles beyond what had been used in conventional composites, and these early packable composites had high viscosity that made them difficult and sometimes impossible to be extruded through the small-bore syringe (Sturdevant, *et al.*, 1993).

According to Manhart et al. (2000) packable composites are also called condensable composites and may offer some technical advantages over the conventional composites, as they could allow easier and convenient application in posterior teeth, and their mechanical properties are significantly different but not consistently better than the properties of the conventional hybrid composites. Peumans et al. (2001) and Klein et al. (2002) explained that the better handling characteristics of the packable composites resulted from their high viscosity property which in turn resulted in easy establishment of the proximal contour of the restoration.

According to Condon and Ferracane (1997) heavily filled composites had higher wear resistance, higher strength and higher fracture toughness when compared with composites that have lower filler content, but Willems et al. (1992) pointed out that the filler content should not exceed 70%, because of technical difficulties and poor handling characteristics.

Choi et al. (2000) conducted a study that showed that the properties of packable composites were similar to the non-packable posterior composites, and polymerisation shrinkage of packable composites was similar or higher than that of non-packable composites. Additionally, Cobb et al. (2000) compared the physical properties of the packable composites to the conventional hybrid composites and concluded that the physical properties of the packable composites were not superior to those of the conventional hybrid composites, in addition to that, the large filler particles may have caused long term problems such as surface roughness and increased wear of the composites.

There are studies which show that the clinical performance of packable resin composites placed using different adhesive systems had satisfactory results as a restoration for posterior teeth after two years (Ernst, *et al.*, 2003; Lopes, *et al.*, 2003).

1.5. Flexural and Compressive strength of Core build-up materials

Flexural strength is the force per unit area at the instant of fracture in a specimen subjected to flexural loading. Flexural strength is also called transverse strength and modulus of rupture is a strength test of a bar supported at each end (Anusavice, *et al.*, 2013). The compressive strength of a material is the internal resistance of the material to breaking under compression (Anusavice, *et al.*, 2013).

Flexural strength tests are considered to be sensitive to surface imperfections such as cracks, voids, and related flaws, which can influence the fracture strength of brittle materials. High flexural strength values reflect a limited tendency for crazing and high resistance to surface defects and erosion. Therefore, flexural and tensile strength are considered to be the most important mechanical properties for the use and evaluation of core materials (Bayindir, 2007).

Several dental materials have been used for core build-up procedures. Most of these materials were not specially developed for this purpose, but, as a consequence of properties such as fluoride release, pleasing colours, adhesion to tooth structure, fast setting rate, choice of curing mechanism, and handling properties, they have found application in core build-up procedures (Saygili & Sahmali, 2002).

Bayindir in 2007 tested the mechanical properties of 5 core build-up materials i.e. composite resin, glass ionomer, resin-modified glass ionomer, amalgam and compomer. The results of the study indicated that the compressive strength varied from 116.34 MPa for glass ionomer to 147.22 MPa for a resin composite. Diametral tensile strength ranged widely from 18.80 MPa for glass ionomer core materials to 147.1 for amalgam. Flexural strength varied 11.76 MPa for compomer to 16.73 for composite resin materials. Light cure composite resin was statistically significantly different for compressive and flexural strength than the other materials tested. Visible light-cured composite is considered to be the best of the materials tested in terms of compressive strength and flexural strength (Bayindir, 2007).

A study in 2000 also found no significant difference in the fracture toughness values for the glass ionomer–based materials (glass ionomer, resin modified glass ionomer) and that both of these were significantly lower than amalgam, titanium-reinforced composite resin, and composite resin with fluoride ($p<.001$). Titanium-reinforced composite resin, composite resin with fluoride, and amalgam materials showed fracture toughness most likely to withstand the stresses generated during mastication (Bonilla, *et al.*, 2000).

Another study was undertaken to find out the best core build up material with respect to their physical properties among resin-based composites (Agrawal & Mala, 2014). Individual compressive, tensile and flexural strength of fiber-reinforced dual cure resin core build up material, silorane-based composite resin, and dual curing composite for core build up with silver amalgam core was used as control. The silorane-based material (Filtek P90) showed the highest flexural strength, but other mechanical properties (compressive and tensile strength) were inferior to dual cure composite materials (LuxaCore and ParaCore) with nanofillers Amalgam and ParaCore composite resin material showed the lowest flexural strength values compared with other materials (Agrawal & Mala, 2014).

Diametral tensile strength of materials was found to be statistically significant with the values for ParaCore were significantly higher than those for all the other materials investigated. It was determined that amalgam is the weakest of all regarding tensile strength. ParaCore composite resin material showed excellent physical properties because it is reinforced with glass fibers; it is a dual cure material that will ensure complete cure, thereby improve the strength of the material. The macroscopic size of the unidirectional fiber bundles used in fiber reinforces the resins and improves their mechanical properties. The presence of fibers affects the fracture process that results in interrupting crack growth progression and thus enhances the fracture toughness of the fiber-reinforced composite material (Agrawal & Mala, 2014).

Resin composites were also found to vary significantly as regards to flexural strength and flexural modulus (Thomsen & Peutzfeldt, 2007). The main explanatory factor for the significant differences in mechanical properties is filler load (Willems, *et al.*, 1992). A positive correlation was also found between the strengths of bond to dentine mediated by the adhesive systems and the flexural strength or flexural modulus respectively, of resin composites (Thomsen & Peutzfeldt, 2007).

The bulk fill material Surefil® SDR™ (Smart Dentin Replacement) (Dentsply, USA, 2011), contains a polymerization modulator, chemically embedded in the center of the polymerizable resin backbone of the SDR™monomer, to lower polymerization shrinkage. The modulator has a high molecular weight. Due to the conformational flexibility around the centered modulator impart, the modulator is supposed to optimize flexibility and network structure of the SDR™ resin (Dentsply, USA, 2011). Investigations on Resin Based Composites (RBCs) with SDR™ technology showed significantly lower shrinkage stress values (Burgess & Cakir, 2010) not only when compared to regular flowable RBCs, but also to nano- and hybrid RBCs or even to silorane-based composites (Ilie & Hickel, 2011a). De Biasi et al. (2010) investigated micro-hardness and raised concerns about its practical use due to its low Vickers hardness (HV). This was also confirmed by Ilie et al. (2011a) where Surefil® SDR™ flow showed the lowest surface hardness when compared to other commonly used RBCs (EsthetX Flow, Filtek Supreme Plus Flow, EsthetX Plus, Filtek Silorane, and Filtek Supreme Plus).

A recent study also found that the mechanical properties of the bulk-fill composites were mostly lower compared with the conventional high viscosity material, and, at best, comparable to the conventional flowable composite. Given the lower mechanical properties of most bulk-fill materials compared to a highly filled nano-hybrid composite, their use for restorations under high occlusal load should be used with caution (Leprince, *et al.*, 2014) and hence may not be suitable as core build-up material.

Significant differences were found in the fatigue strength between various core materials tested, which can be explained by the different filler loading, because the higher the filler loading, the stronger the material. Grandio Core showed high fatigue strength possibly because of the presence of urethane dimethacrylate (UDMA) in the resin matrix of Grandio Core and CoreXflow may contribute to the superior mechanical properties (Zankuli, *et al.*, 2015). This was also supported by a previous study that reported that replacing bisphenol A-glycidyl methacrylate with UDMA resulted in improved flexural and tensile strength of resin composites (Tolosa, *et al.*, 2005). Bright Flow had significantly lower compressive strength than Grandio Core and CoreXflow because of it is lower filler loading. The filler loading of Grandio Core and CoreXflow is higher than the other materials. However, the fatigue strength of Grandio Core was significantly higher than CoreXflow possibly due to the filler loading. Grandio Core has a filler weight loading of 77% compared to CoreXflow’s 69% by weight (Zankuli, *et al.*, 2015).

The continuous repeated and small mechanical stresses generated by teeth during mastication result in core restorations undergoing fatigue and eventually fracture. Therefore, it is important to study the fatigue behaviour particularly of core build-up materials. CoreXflow consists of two-components, base and catalyst, which when mixed forms a dual-cured, highly filled, composite resin core build-up and material for the cementation of posts (Dentsply, USA, 2016). Compressive strength reflects the resistance of a core material to masticatory and parafunctional forces.

Filler size is only one of several parameters affecting the overall properties of a resin-composite. The filler type, shape and amount, as well as the efficient coupling of fillers and resin matrix, contribute to the material performance. Properties such as compressive or flexural strength, hardness and Young's modulus improve as the filler content increases. At the same time polymerization shrinkage decreases (Masouras, *et al.*, 2008).

Filtek Supreme XTE Universal Restorative (3M ESPE, USA, 2010) is a visible light-activated composite designed for use in anterior and posterior restorations. The resin system is slightly modified from the original Filtek™ Z250 Universal Restorative and Filtek™ Supreme Universal Restorative resin. The resin contains bis-GMA, UDMA, TEGDMA, and bis-EMA resins. To moderate the shrinkage, PEGDMA has been substituted for a portion of the TEGDMA resin in Filtek Supreme XT restorative. The fillers are a combination of non-agglomerated/non-aggregated 20 nm silica filler, non-agglomerated/non-aggregated 4 to 11 nm zirconia filler, and aggregated zirconia/silica cluster filler (comprised of 20 nm silica and 4 to 11 nm zirconia particles). The Dentin, Enamel and Body (DEB) shades have an average cluster particle size of 0.6 to 10 microns. The Translucent (T) shades have an average cluster particle size of 0.6 to 20 microns. The inorganic filler loading is about 72.5% by weight (55.6% by volume) for the Translucent shades and 78.5% by weight (63.3% by volume) for all other shades (3M ESPE, USA, 2010).

The compressive strength of Filtek™ Supreme XTE Universal Restorative (DEB shades) is comparable to the T shades and Filtek™ Supreme XT Universal Restorative. Filtek Supreme XTE restorative has statistically significantly higher compressive strength than Gradia Direct X. The flexural strength of the DEB shades of Filtek Supreme XTE restorative is comparable to the T shades and Filtek Supreme XT restorative. The flexural strength of Filtek Supreme XTE restorative is significantly higher than the microfills Durafill VS and Renamel Microfill. It is also higher than the universal restoratives CeramX Mono, Estelite Sigma Quick, EsthetX

HD, Gradia Direct X, Grandio, Herculite XRV Ultra, Premise, Tetric EvoCeram and Venus (3M, ESPE, USA, 2010).

1.6. Shear Bond strength

Bond strength testing has been traditionally accomplished by creating one test specimen per tooth or tooth surface which is then loaded to failure in either shear (SBS), tensile (TBS), or fracture-based manner. By definition, the ideal bond-strength test should be in the first place easy (meaning low technique-sensitivity) and relatively fast (Armstrong, *et al.*, 2010). In general, advantages of ‘laboratory testing’ are, among others, (1) the quickness to gather data on a specific parameter/property, (2) the relative ease of the test methodology commonly used, (3) the possibility (and necessity) to measure one specific parameter, while keeping all other variables constant, (4) to be able to directly compare the performance of a new and/or experimental material/technique with that of the current ‘gold-standard’, (5) to be able to test simultaneously many (of course within certain limits) experimental groups within one study set-up, and (6) to be able to mostly use relatively unsophisticated and inexpensive test protocols/instruments. The final objective of a laboratory test should obviously be to gather data in prediction of the eventual clinical outcome (Van Meerbeek, *et al.*, 2010).

Bond strength can be measured statically using a Macro- or Micro-test set-up, basically depending upon the size of the bond area. The Macro-bond strength, with a bond area larger than 3mm, can be measured in ‘shear’, ‘tensile’, or using a ‘push-out’ protocol.

The most commonly used test is the shear bond-strength technique (Burke, *et al.*, 2008), and was found to have been used in 26% of scientific papers reporting on bond strength. Meta-analysis of factors involved in bond-strength testing revealed a significant influence of various parameters, like those related to the dentin substrate (i.e. nature of teeth), to the composite and bonding area (i.e. composite stiffness), to the storage conditions of the bond assemblies (i.e. thermo-cycling), and to the test design (i.e. crosshead speed) (Leloup, *et al.*, 2001). In particular, a strong correlation was found between the mean bond strength and the failure mode: the higher the bond strength, the higher the rate of cohesive failure.

Also the type of composite is crucial. A stiffer composite will result in different stress distributions at the interface and lead to a higher apparent bond-strength value. The most frequently ignored guideline in the test protocol following the ISO/TS 11405 specification (2003) is that 'a limitation of the bonding area is important'. Nevertheless, the shear bond-strength test probably remains a very popular test to screen new adhesive formulations on their bonding effectiveness (Van Meerbeek, *et al.*, 2010).

1.7. Shear bond strength of core build-up materials

A core build up material must exhibit good adhesion to dentine in the absence of micro-leakage, to prevent dislodgement of the restoration (Xie, *et al.*, 2008). Shear bond strength is greatly affected by a material's degree of polymerization shrinkage which influences its adhesion to dentine. The amount of intact dentine also affects the bond strength of the material (Markovic, *et al.*, 2011).

Flowable composites compared to glass ionomer have greater shear bond strength when used in combination with their respective adhesive systems. The authors suggest that the lowered viscosity of the material renders it more flexible to resist fractures. (Davidson, *et al.*, 1984). The fluidity of flowable composites allows it to act as shock absorbers, which counter acts any polymerization stresses (Dietschie, *et al.*, 2003; Li, *et al.*, 2006). Several new formulations of flowable composites have been introduced in recent years for use as core materials. These include Surefill SDR Flow, CoreXflow and Filtek XT Flow. CoreXflow has been shown to be successful when used with its XP bonding system around fiber reinforced posts. The material demonstrated good bond strength and minimal nanoleakage *(*Mazzoni, *et al.*, 2009).

Various dual-cured resin composite build-up restoratives that combine the advantages of light curing and self curing mechanisms have been introduced, with the rationale to develop a material capable of reaching higher degree of polymerization in either the presence or absence of light, and overcome the limitations of reduced interlayer strength (Kournetas, *et al.*, 2011). SBS was not negatively affected by thermocycling. A recent study comparing the shear bond strength of 3 dual-cure core build-up materials; Multi-Core dual-cure resin based core build-up material showed the highest mean SBS compared to FluoroCore and ParaCore. (Jain, *et al.*, 2015).

Thus a review of the literature of core build-up material shows that although there are numerous studies regarding the physical properties of these core build-up materials, there are only a few that were designated to determine the flexural strength and shear bond strength of these materials. There are also limited studies evaluating and comparing the flexural strength and shear bond strength of the core build-up material specifically designed for core build-up material to conventional composite restorative material used as core build-up material. Furthermore, clinically many practitioners generally use conventional composite material for core build-up instead of core build-up material specifically designed for core build-up. Therefore; the purpose of this study was to evaluate and compare materials specifically designed as core build-up materials to the conventional restorative composites being advocated as core build-up materials.

CHAPTER 2

Aims and Objectives

2.1. Aims

The aim of the study was to evaluate and compare the physical and adhesive properties of 4 different resin core build up materials, namely, 2 specifically designed as core build-up material (ParaCore and CoreXflow) and 2 conventional restorative composites used as core build-up material (Filtek Supreme XTE and SDR Flow).

2.2 Objectives

1. To determine the flexural strength for 4 core build-up materials.
2. To determine the shear bond strength for 4 core build-up materials when bonded to healthy dentin and enamel.
3. To compare the shear bond strength and flexural strength of these materials.
4. To study the failure patterns of the materials tested using a light microscope (40 x magnification) for the shear and flexural test failures.

2.3. Null Hypothesis

The null hypothesis of this study was that there is no significant difference in the flexural strength and shear bond strength of the conventional resin composite material that have been advocated as core materials and those specifically designed as core build-up materials.

2.4. Ethical considerations

This research proposal was presented to the Research Committee of the Faculty of Dentistry of the University of Western Cape and to the Senate Research Committee for ethics approval and for registration as a research project (Project no SHD 2014/12, approved on 22/10/2014). This research was a laboratory study that involves the use of extracted teeth. Patient consent was sought from patients attending the Department of Oral and Maxillo-facial Surgery, UWC. A consent form (Appendix 1: Patient information sheet) was obtained from each patient regarding the use of the extracted teeth before commencement of the study. The donation of teeth from patients was on a voluntary basis and full disclosure was made to patients regarding their rights as explained in the consent form. This research was not supported by any research grant from any foundation or company, and the researcher declares that there is no conflict of interest. This research was self-funded.

CHAPTER 3

Materials and Methods

This was an in-vitro study to test and compare the flexural strength and shear bond strength of 4 core build-up materials (Table 4 & 5).

3.1 Study Materials and collection of samples

120 extracted maxillary central incisor teeth were collected from the Oral Surgery Department (University of the Western Cape) after consent was obtained from the patients. All teeth collected were evaluated to ensure the absence of any carious lesions. Teeth were cleaned and stored in distilled water at 37°C, until time of crown preparation and material placement. Teeth were stored for no longer than 3 months.

Table 4: List of Materials, Manufacturer and Composition.

Materials	Manufacturer	Composition
ParaCore	Coltene	Methacrylates, barium glass, silica
CoreXflow	Dentsply	Urethane Dimetracrylate, Fluoroaluminosilicate Glass, Silicon Dioxide
Filtek Supreme XTE	3M ESPE	UDMA, TEGDMA, BIS-EMA, inorganic fillers (silica nanofillers, zirconia/silica nanoclusters)

Surefill SDR Flow	Dentsply	Modified Urethane dimetracrylate, TEGDMA, alumina-fluoro-silicate glass

Table 5: Composition of Materials and respective adhesives according to Manufacturers

Adhesive	**Core Material**	**Manufacturer**	**Composition of Adhesive**	**Composition of Core Material**	**Adhesive Approach**
Scotchbond Universal	Filtek Supreme XTE	3M ESPE	MHP Phosphate Monomer, Dimethacrylate resins, Hema, Vitrebond Copolomer, Filler, Ethonal, Water, Initiators	UDMA, TEGDMA, BIS-EMA, inorganic fillers (silica nanofillers, zirconia/silica nanoclusters)	Combined Total etch, Self etch and Selective-etch
ParaBond Adhesive A & B	ParaCore	Coltene	Adhesive A: Methacrylates, Meleic Acid, Benzoyl Peroxide Adhesive B: Ethonol, Water, Initiators	Methacrylates, barium glass, silica	Chemically cured, Self-conditioning
XP Bond	Surefill SDR	Dentsply	XP Bond: PENTA, TCB, HEMA, TEGDMA, UDMA, tert-butanol, nanofiller, CQ, stabilizer	Modified Urethane dimetracrylate, TEGDMA, alumina-fluoro-silicate glass	Etch and rinse
XP Bond	CoreXflow	Dentsply	XP Bond: PENTA, TCB, HEMA, TEGDMA, UDMA, tert-butanol, nanofiller, CQ, stabilizer	Urethane Dimetracrylate, Fluoroaluminosilicate Glass, Silicon Dioxide	Etch and rinse

ParaCore

ParaCore is a composite-based, dual-cured, radio-opaque core build-up material. ParaCore is also suitable for use in cementing root posts and indirect restorations. ParaBond adhesive is a chemical cured, self-conditioning adhesive system for enamel and dentine speciafically for use with ParaCore. It consists of a non-rinse conditioner and a chemical-curing adhesive (Adhesive A and B) (Figure 3).

Figure 3: ParaCore & Adhesive A & B (Coltene, Switzerland, 2016)

Composition:

ParaCore contains:

- Methacrylates
- Fluoride
- Barium glass
- Amorphous silica

ParaBond Adhesive A contains:

- Methacrylates
- Maleic Acid
- Benzoyl peroxide

ParaBond Adhesive B Contains:

- Ethanol
- Water
- Initiators

Technical Data (Complies with ISO 4049:2000):

- Average Particle size: 2μm
- Range of particle size: 0.1-5.0 μm
- Percentage by volume of total inorganic filler: approx. 50%
- Percentage by weight of total inorganic filler: approx. 68%

Core X Flow (Dentsply, USA)

CoreXflow (Figure 4), consists of two-components, base and catalyst, which when mixed forms a dual-cured, highly filled, composite resin core build-up and post-cementation material. The material uses a biocompatible urethane resin and is supplied in a tooth-coloured shade which is ideal in situations where esthetics is of primary concern.

Figure 4: CoreXflow and XP Bond (Dentsply, USA, 2016)

Composition:

- Urethane Dimethacrylate
- Di- & Tri-functional methacrylates
- Barium Boron Fluroaluminosilicate glass
- Camphorquinone Photoinitiator
- Photoaccelerators
- Silicon Dioxide
- Benzoyl Peroxide

Filtek Supreme XTE

3M™ ESPE™ Filtek™ Supreme XTE Universal Restorative (Figure 5), is a visible light-activated composite designed for use in anterior and posterior restorations. All shades are radio-opaque. A dental adhesive, such as those manufactured by 3M ESPE, is used to permanently bond the restoration to the tooth structure. The restorative material is available in a wide variety of Dentin, Body, Enamel and Translucent shades. It is packaged in syringes and single-dose capsules.

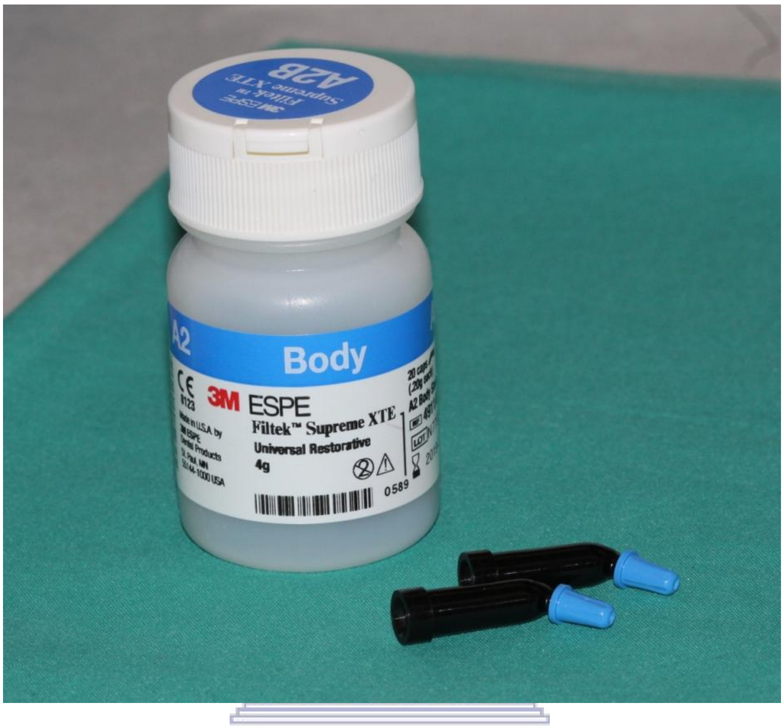


Figure 5: Filtek Supreme XTE (3M ESPE, 2010)

Composition:

The resin system is slightly modified from the original Filtek™ Z250 Universal Restorative and Filtek™ Supreme Universal Restorative resin. The resin contains bis-GMA, UDMA, TEGDMA, and bis-EMA resins. To moderate the shrinkage, PEGDMA has been substituted for a portion of the TEGDMA resin in Filtek Supreme XT restorative. The fillers are a combination of non-agglomerated/non-aggregated 20 nm silica filler, non-agglomerated/non-aggregated 4 to 11 nm zirconia filler, and aggregated zirconia/silica cluster filler (comprised of 20 nm silica and 4 to 11 nm zirconia particles). The Dentin, Enamel and Body (DEB) shades have an average cluster particle size of 0.6 to 10 microns. The Translucent (T) shades have an average cluster particle size of 0.6 to 20 microns. The inorganic filler loading is about 72.5% by weight (55.6% by volume) for the translucent shades and 78.5% by weight (63.3% by volume) for all other shades.

SDR Flow (Dentsply USA)

SDR Flow is a posterior Bulk fill flowable base that is one-component, fluoride-containing, visible light-cured radio-opaque resin composite restorative material. It is designed to be used as a base in Class l and ll restorations. It is also suitable as a stand-alone restorative material in non-occlusal-contact applications. SDR material has handling characteristics typical of a ‘flowable’ composite, but can be placed in 4 mm increments with minimal polymerization stress. It is available in one universal shade. When used as a base/liner, it is designed to be overlayed with a methacrylate based universal/posterior composite for replacing missing occlusal or facial enamel (Figure 6).

Figure 6: SDR Flow (Dentsply, USA, 2011)

Composition of the material according to the manufacturers was as follows:

- Resin matrix: SDR patented urethane dimethacrylate resin, dimethacrylate resin and di-functional diluent resin.
- Inorganic fillers (68% by weight and 45% by volume): barium and strontium alumino-fluoro-silicate glasses.
- Photointiating system.
- Colourant.

3.2. Flexural Strength Test

3.2.1. Preparation of test specimens

Moulds were made using laboratory putty and cold cured acrylic resin, for the preparation of test specimens 25±2 mm x 2.0±0.1 mm x 2.0±0.1 mm (Figure 7), according to ISO 4049:2009 for flexural strength testing (Figure 7).

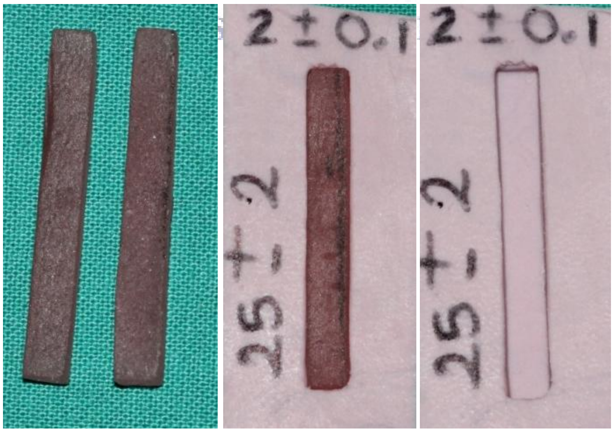


Figure 7: Mould for flexural strength test specimens (ISO 4049:2009)

48 Specimens were prepared and divided randomly into 4 groups with 12 specimens per material. The materials were prepared in accordance with the manufacturer’s instructions and immediately placed as evenly as possible without bubbles or voids in the moulds with a slight

excess. A transparent film was placed on the material in the mould and this was covered with a glass slab. Pressure was applied to displace the excess material (Figures 8 & 9). The specimens were then cured according to the manufacturer's instructions (Figure 9). Specimens were light cured for 20 seconds using a DeepCure LED curing light (3M ESPE, USA). The light was checked for light output using a Cure Rite light meter (Dentsply, USA). The light output was recorded at 1000 mWatts/cm. The curing light was checked after every 12 samples. All specimens were placed in distilled water maintained at 37±1 °C for 24 hours before testing.

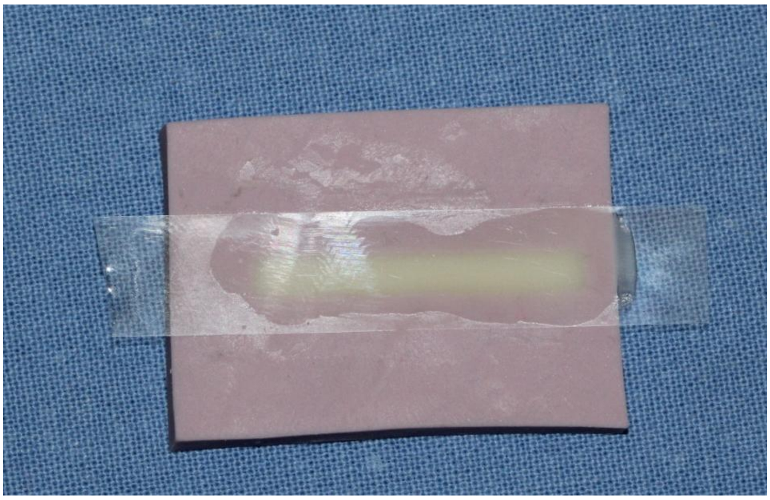


Figure 8: Transparent film to remove excess material.

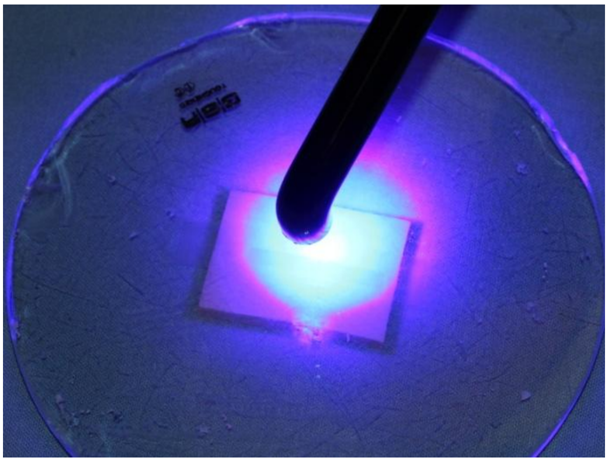


Figure 9: Glass slab added to apply pressure and curing of material.

3.2.2 Testing specimens (Flexural strength)

The specimens (Figure 10) were tested using a Tinius Olsen H10KT Universal testing machine (Horsham, USA) (Figure 11). Each specimen was placed and secured in a jig (Figure 12). The angle of load for the specimens was at 90° to the long axis. The point of contact was at the centre of the specimen length. Load was applied at a crosshead speed of 1 mm/min on the core material until failure occurs. The force that was applied at time of failure or fracture was recorded in Newton (N) (Figure. 12).

Flexural strength was then calculated using the following equation and recorded in megapascals (MPa): ISO 4049:2009

$$\sigma = 3PL/2wt^2$$

Where P is the maximum load exerted on the specimen; L is the distance (mm) between the supports ±0.01 mm; w is the width (mm) of specimen immediately prior to testing; and t is the thickness (mm) of specimen measured immediately prior to testing. The experimental variables of specimen size, shape, testing configuration, fabrication procedure, temperature, humidity, storage time, storage temperature, strain rate, and set time were all standardized in this study. All specimens were treated identically throughout this study, which was based on American Dental Association (ADA) Specification No. 27.

Figure 10: Cured specimen.

Figure 11: Tinius Olsen H10KT Universal Testing machine (Horsham, USA)

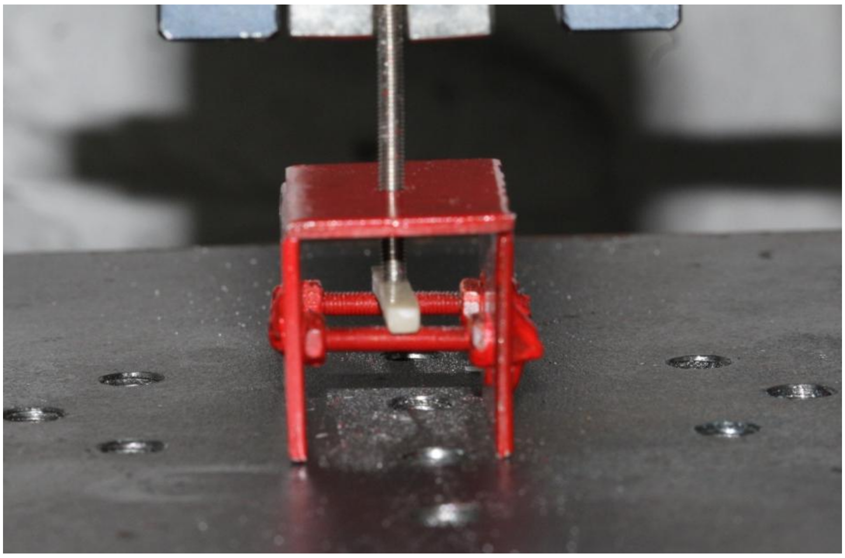


Figure 12: Testing Flexural strength.

3.3. Shear Bond Strength Testing

3.3.1. Cavity Preparation and placement of the core material.

120 teeth were used for this part of the study. The teeth were randomly divided into 4 groups of 30 teeth each (n=30); based on the restorative materials being tested. A cavity preparation (Figure 13) was made in the dentine with a tungsten carbide fissure bur (SS White, Lakewood, USA) and water- sprayed high speed hand piece (NSK, Japan). The tooth was sectioned half the width and length of the anatomic crown of the teeth. The size of the section was 7±0.5 mm, inciso-cervically and 3.5±0.3 mm in a labio-palatal direction. The teeth were sectioned parallel to the incisal edges, 1 mm above the cementoenamel junction. The protocol was adopted from a study by Combe et al (1999); which evaluated the mechanical properties of direct core materials (Figure 14).

Figure 13: Cavity Preparation for central incisor teeth.

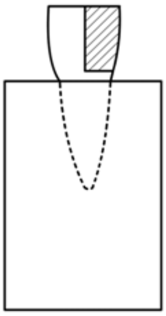


Figure 14: Diagram of tooth preparation and restoration (Combe et al., 1999).

Vitremer was placed in all cavities with pulpal exposure prior to core build up. The burs were changed after every 5 cavity preparations. The dentine surfaces were polished using a medium grit (light blue), Sof-Lex disc (3M ESPE, Dental Products, Germany) and mandrel. Each tooth root was aligned with the help of a surveyor (Dentalfarm, Torino, Italy) and mounted with acrylic resin into a PVC tube with a diameter of 20 mm, 2 mm below the cementoenamel junction (Figures 15 & 16).

Figure 15: Surveyor used to align the teeth parallel (Dentalfarm, Torino, Italy)

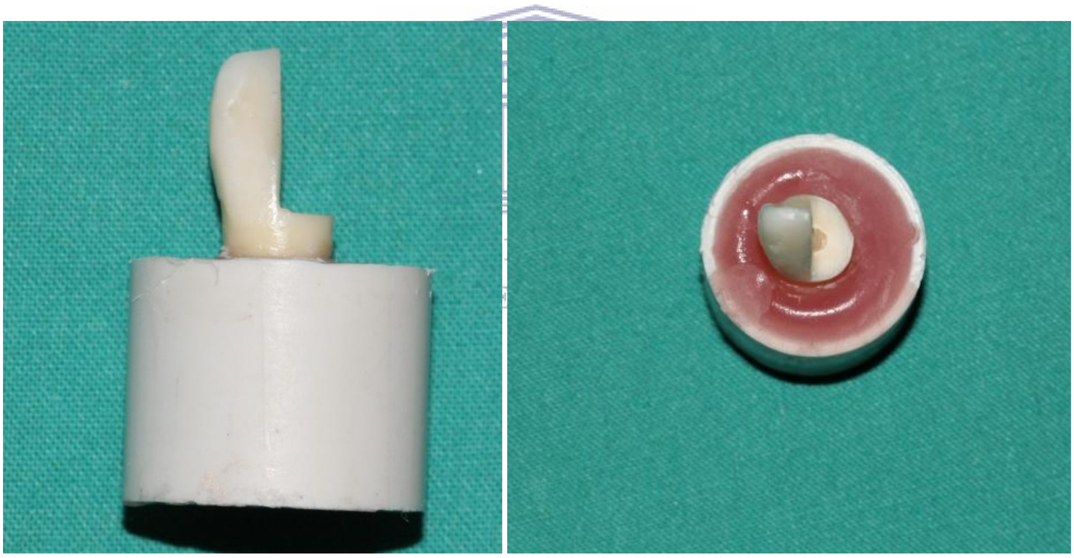


Figure 16: Parallel alignment of teeth in acrylic resin and PVC tubes.

All teeth and materials were randomly divided into 4 groups and materials were manipulated according to manufacturer's instructions to build up the core. Subsequently, the specimens were stored in distilled water at 37 °C for 24 hours prior to testing (Figure 17).

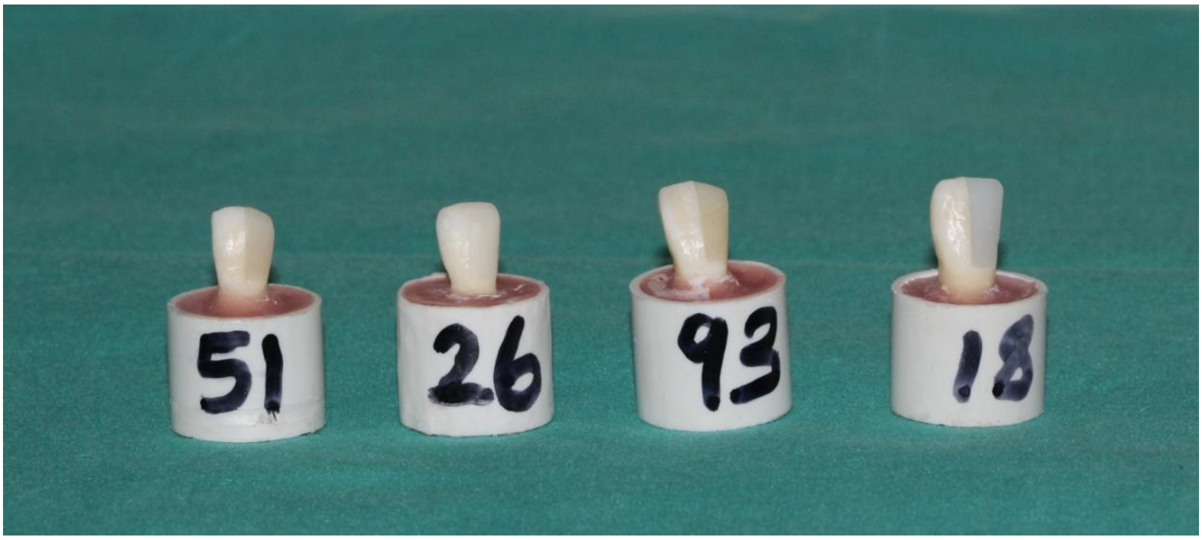


Figure 17: Teeth restored according to manufacturer instructions and randomly divided.

3.3.2. Testing of the core materials (Shear Bond strength)

This experiment was performed using a Tinius Olsen H10KT Universal testing machine (Horsham, USA) (Figure 11).

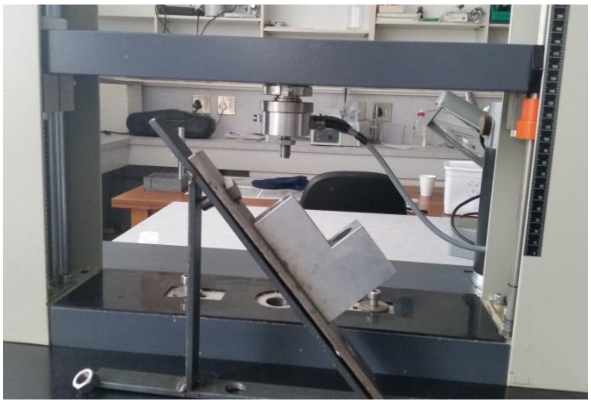


Figure 18: Specimen supported on a Jig.

Each specimen was placed and secured in an adapted jig (Figure 18). The angle of load for the incisor teeth was at 90° to the long axis of the tooth. The point of load was 2 mm apical to the incisal edge (Figure 19). This angle represented the axis formed by the maxillary and mandibular teeth in a class I dentoalveolar relationship (Figure 20).

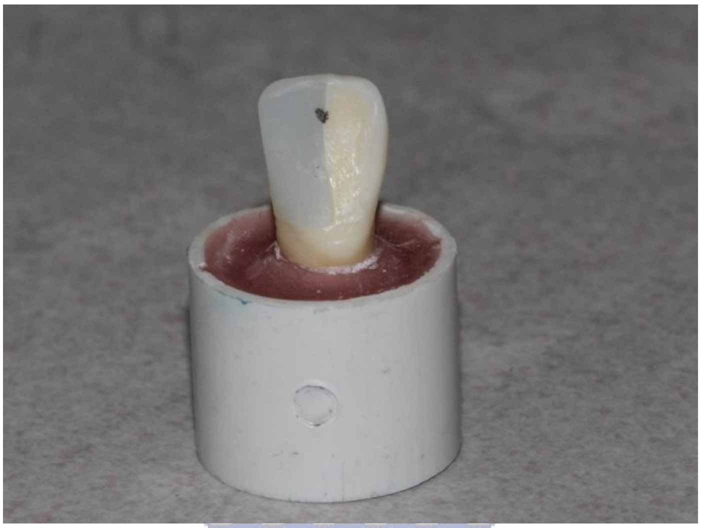


Figure 19: Point of load application.

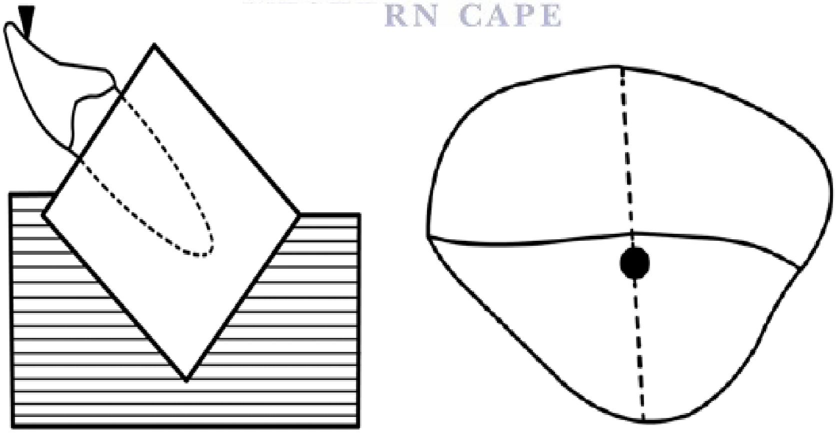


Figure 20: Angle of load of the maxillary and mandibular incisor teeth (Markovic, et al., 2011)

Load was applied at a crosshead speed of 0.5mm/min on the palatal surface, at the adhesive interface formed between the dentin and test material. The load was applied half on the tooth and half on the core material until failure occurs. The force that was applied at time of failure or fracture was recorded in megapascals (MPa).

3.4 Evaluation of failure patterns

10 randomly selected specimens from all 4 groups were examined using a Light Microscope (Wild Heerbrugg M5, Switzerland) to study the failure patterns of the materials tested (Figure 21 & 22). 2 operators were used to independently assess the failure patterns. Operators were calibrated before assessing the samples under light microscope of 20x's magnification. If there are discrepancies between the operators with the samples a consensus was reached and documented.

Figure 21: Light microscope: Wild Heerbrugg M5 (Switzerland)

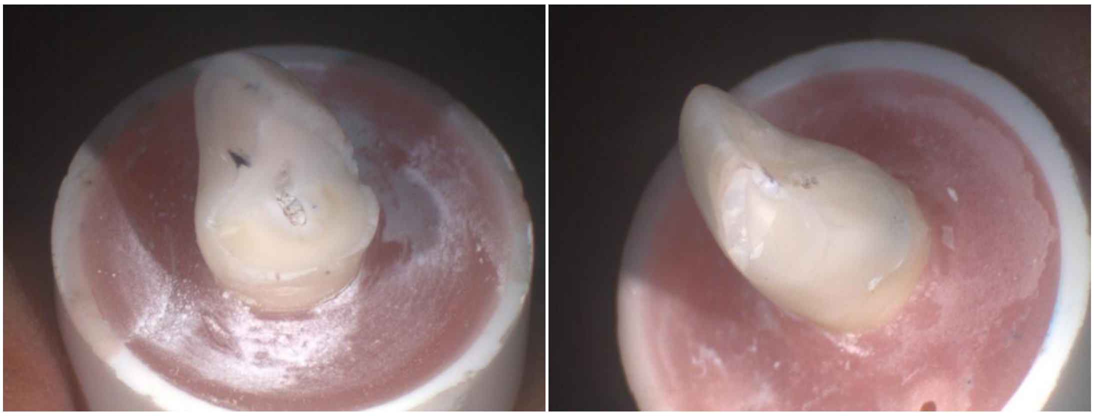


Figure 22: Failure modes under light microscope

3.5. Statistical Analysis

The data was captured for statistical analysis, using a statistical program (SPSS version 21, IBM, USA). Data was evaluated using the standard descriptive and comparative statistics. The shear bond strength and flexural strength was calculated at the ratio of maximum load recorded at failure in megapascals.

CHAPTER 4

Results

4.1 Data analysis

The results were recorded on a Microsoft Excel 2010 spreadsheet (Microsoft Corporation, USA) and the data was analysed using SPSS Statistical Software Ver21 (IBM, USA). A non-parametric analysis was performed at significance level of $p < 0.05$ to compare the shear bond strength and flexural strength of the various materials. The results are presented in tables and graphs (Box and Whisker plots).

4.2. Results

4.2.1. Flexural strength

48 Specimens which were divided into 12 specimens per material were tested to determine the flexural strength of the 4 core build-up materials. The number of observations of strength measurement of four different materials is presented in Table 6.

Table 6: Flexural Strength measurement the materials.

Material				
		Frequency	Percent	Cumulative Percent
Valid	Filtek	12	25.0	25.0
	Surefill	12	25.0	50.0
	CoreXflow	12	25.0	75.0
	Paracore	12	25.0	100.0
	Total	48	100.0	

The mean flexural strength (FS) was highest for CoreXflow followed by ParaCore. The Mean FS values for CoreXflow, ParaCore, SDR Surefill and Filtek Supreme XTE obtained were 383.5 Mpa, 356.5 Mpa, 324.1 Mpa and 311.7 Mpa respectively (Table 7).

Table 7: Descriptives of Filtek, Surefill, CoreXflow and ParaCore

Mpa						
Material	Mean	N	Std. Deviation	Median	Minimum	Maximum
Filtek	311.7417	12	42.82345	297.6500	261.00	390.40
Surefill	324.1091	12	24.32893	314.0000	293.90	365.60
CoreXflow	383.5750	12	33.99778	384.3500	331.40	443.90
Paracore	356.5909	12	14.33642	357.6000	332.80	381.00
Total	344.1630	48	41.69655	350.0500	261.00	443.90

A significant difference in FS was observed between the materials (One-way ANOVA and Dunn-Sidak ($p<0.05$) (Figures 23 & 24). No significant difference was found between the 2 composite restorative materials, Filtek and SDR SureFill ($p>0.05$) and between the 2 core build-up materials, CoreXflow and ParaCore ($p>0.05$). A significant difference was found between Filtek & SDR and CoreXflow & ParaCore ($p<0.05$).

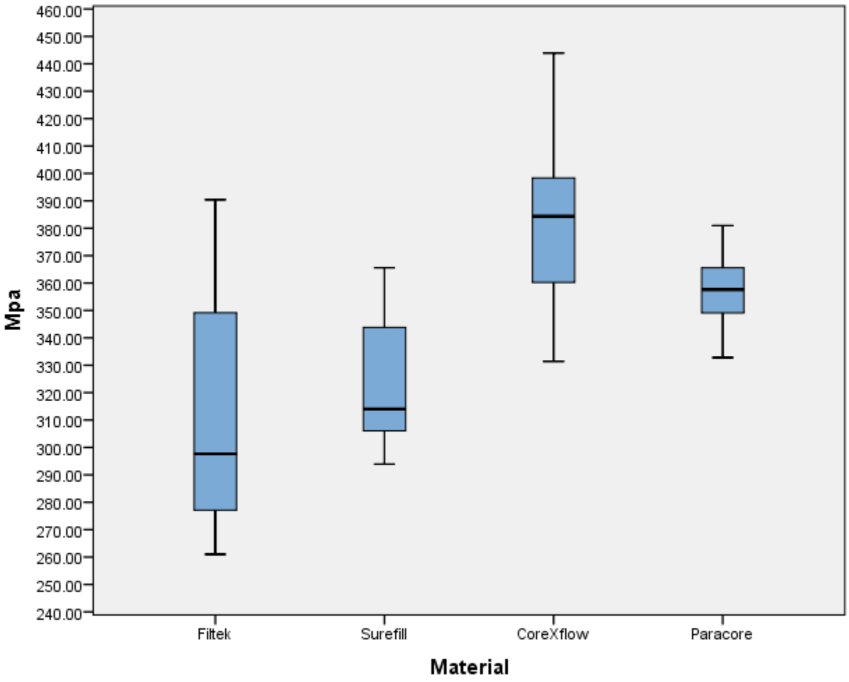


Figure 23: Boxplot: Comparison of flexural strength.

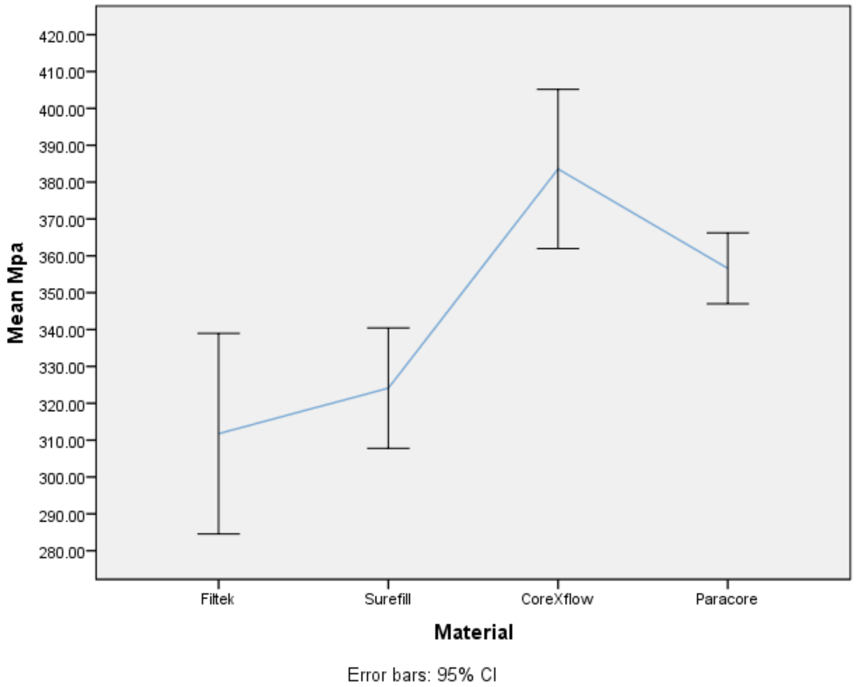


Figure 24: Means of flexural strength with 95% CI per material.

A nonparametric One Way Anova (Kruskal-Wallis) was used to analyse the differences between the materials (Table 8).

Table 8: Descriptives of Kruskal-Wallis per material.

Ranks			
	Material	N	Mean Rank
Mpa	Paracore	12	27.82
	CoreXflow	12	36.00
	Filtek	12	13.83
	Surefill	12	16.09
	Total	48	

The mean rank was the highest for CoreXflow followed by ParaCore. The Mean rank for CoreXflow, ParaCore, SDR and Filtek obtained were 36 Mpa, 27.8 Mpa, 16 Mpa and 13.8 Mpa respectively (Table 8).

Table 9: Pairwise comparisons (Dunn-Sidak)

Pairwise Comparisons of Material		
Sample 1-Sample 2	Std. Error	Sig.
Filtek-Surefill	5.602	.687
Filtek-Paracore	5.602	.013
Filtek-CoreXflow	5.479	.000
Surefill-Paracore	5.723	.040
Surefill-CoreXflow	5.602	.000
Paracore-CoreXflow	5.602	.144

Multiple comparisons were performed using the Pairwise comparisons test (Dunn-Sadak) to determine if there were any significant differences in flexural strength of the materials tested (Table 9). When flexural strength was analysed there was a significant difference between the materials specifically designed as core build-up materials (CoreXflow and ParaCore) and the conventional composite materials being advocated as core build-up materials (Filtek Supreme XTE and SDR Surefill) ($p<0.05$, Dunn-Sadak). No significant difference in flexural strength was found between the conventional composites ($p>0.05$). No significant difference was also found between the core materials (CoreXflow and ParaCore) ($p>0.05$). A significant difference was found between Filtek and Paracore and Filtek and CoreXflow ($p<0.05$). A significant difference was also found between SDR and Paracore and SDR and CoreXflow ($p<0.05$).

4.2.2. Shear Bond Strength

The mean Shear Bond Strength (SBS) was highest for SDR followed by ParaCore. The Mean SBS values for SDR, ParaCore, Filtek Supreme XTE and CoreXflow, obtained were 147.6 N, 142 N, 137 N, 119.2 N respectively (Table 10).

Table 10: Mean SBS per material

	Dependent Variable: SBS					
Material	N	Mean	Std. Dev	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
ParaCore	10	142.000	36.08	8.691	124.318	159.682
CoreXFlow	9	119.250	16.99	9.717	99.481	139.019
Filtek	10	137.200	27.00	8.691	119.518	154.882
Surefill	9	147.667	24.04	9.161	129.029	166.305

No statistical significance difference in shear bond strength were observed between the materials tested (One-way ANOVA and post hoc Tukey's test ($p<0.05$) (Figures 25 & 26).

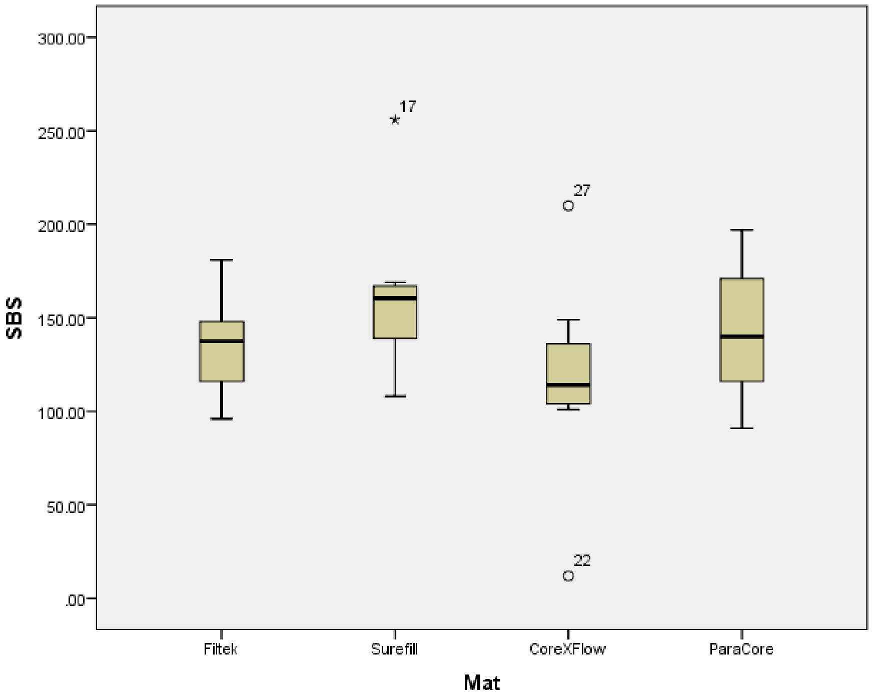


Figure 25: Boxplot: Comparison of Shear Bond Strength.

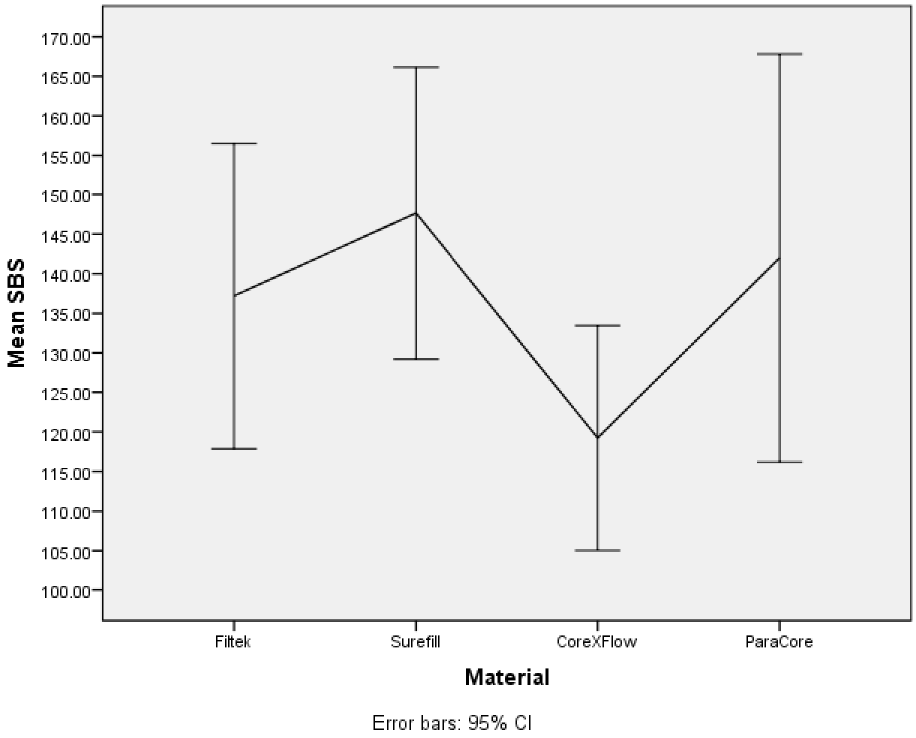


Figure 26: Means of strength with 95% CI per material.

Table 11: Pairwise comparison between materials

Dependent Variable: SBS

(I) Material	(J) Material	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Filtek	Surefill	-10.467	12.627	1.000	-45.909	24.976
	CoreXFlow	17.950	13.036	1.000	-18.640	54.540
	ParaCore	-4.800	12.291	1.000	-39.297	29.697
Surefill	Filtek	10.467	12.627	1.000	-24.976	45.909
	CoreXFlow	28.417	13.354	.245	-9.066	65.899
	ParaCore	5.667	12.627	1.000	-29.776	41.109
CoreXFlow	Filtek	-17.950	13.036	1.000	-54.540	18.640
	Surefill	-28.417	13.354	.245	-65.899	9.066
	ParaCore	-22.750	13.036	.542	-59.340	13.840
ParaCore	Filtek	4.800	12.291	1.000	-29.697	39.297
	Surefill	-5.667	12.627	1.000	-41.109	29.776
	CoreXFlow	22.750	13.036	.542	-13.840	59.340

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multiple comparisons were performed using the Pairwise comparisons test (Dunn-Sadak) to determine if there were any significant differences in flexural strength of the materials tested (Table 11). No significant difference in shear bond strength were found between the materials tested (p>0.05).

4.2.3. Mode of failure

The failure mode patterns were classified as two types:

Type 1: Cohesive failure in dentine

Type 2: Adhesive failure at luting-dentine interface

Table 12: Patterns of failures of different materials.

Material	**Cohesive Failure %**	**Adhesive Failure%**
ParaCore	25	75
CoreXflow	45	55
Filtek	30	70
SDR	60	40

ParaCore failed predominantly adhesively (75%) with the lowest cohesive failures (25 %). This was followed by Filtek which failed at 70 % cohesively. The highest cohesive failures were observed for SDR at 60 %. Whereas, CoreXflow showed an almost even distribution between the specimens failure patterns (Table 12).

CHAPTER 5

Discussion

A core build-up is a restoration placed to provide the foundation for a restoration that will endure the masticatory stress that occurs in the oral cavity for prolonged periods and to provide satisfactory strength and resistance to fracture before and after crown preparation in severely damaged teeth (Combe, *et al.*, 1999). The selection of materials is based primarily on ease of handling with due consideration being given for mechanical properties and manipulative variables. Among mechanical properties compressive strength of core materials is important because cores usually replace a large bulk of tooth structure and they should provide sufficient strength to resist intraoral compressive and tensile forces that are produced in function and parafunction (Anusavice, *et al.*, 2013). Flexural strength is used to evaluate the strength of the material and the amount of the distortion expected under bending stress (Anusavice, *et al.*, 2013). A core build up material must also exhibit good adhesion to dentine in the absence of micro-leakage, to prevent dislodgement of the restoration (Xie, *et al.*, 2008). Shear bond strength is greatly affected by a material's degree of polymerization shrinkage which influences its adhesion to dentine.

Under the conditions of the present study, there was a significant difference in flexural strength of the conventional restorative resin composite material that have been advocated as core materials (Filtek Supreme XTE & SDR Surefill) and those specifically designed as core build up materials (CoreXflow & ParaCore). These results reject the null hypothesis that there was no significant difference in the physical properties of these materials. The mean flexural strength (FS) was highest for CoreXflow followed by ParaCore although this was statistically not significant. Similarly with the composite restorative group there was no significant difference between Filtek and SDR.

An ideal core build-up material should have physical properties similar to those of tooth structure, as a restored tooth tends to transfer stress differently than an intact tooth (Jain, *et al.,* 2015). Finan (2013) concluded his study by stating that the mechanical properties of composites are greatly influenced by alterations in their filler size and distribution of the filler. The filler component has a great influence on the dental composite’s ability to resist crack initiation and propagation, as well as its response to abrasion and contact loading to wear.

According to Condon and Ferracane (1997) heavily filled composites have had higher wear resistance, higher strength and higher fracture toughness when compared with composites that have lower filler content, but Willems et al. (1992) pointed out that the filler content should not exceed 70%, because of technical difficulties and poor handling characteristics (Condon & Ferracane, 1997; Willems, *et al.,* 1992).

A study of dynamic fatigue using biaxial flexure testing revealed that composites with a broader distribution of filler particle sizes had a higher resistance to subcritical crack growth (Omaghi, *et al.,* 2012). A follow-up study by this group examined the fracture toughness, initial fracture strength and cyclic fatigue resistance of the same composites, and showed that the presence of larger particles led to enhanced fracture toughness owing to greater deflection energy-dissipating mechanisms (Omaghi, *et al.,* 2014). However, composites with smaller fillers had improve fatigue resistance owing to the fact that they were more creep compliant, thus allowing them to dissipate lower load cyclic energy more efficiently. Thus composites with larger fillers would be expected to be more resistant to the rapid introduction of high contact forces, such as when teeth impact on one another or the patient bites down rapidly on a hard object, while those with smaller fillers would be superior under the conditions of lower cyclic stress, such as normal chewing. Although all the tested materials are indicated for core build-up according to the manufacturers their difference in flexural strength might be attributed to the differences in the composition of these materials.

ParaCore is a composite-based, dual-cured, radio-opaque material specifically designed for core build-up. ParaBond adhesive is a chemical cured, self-conditioning adhesive system for enamel and dentine. The technical data provided for ParaCore consists of average particle size: 2µm; Range of particle size: 0.1-5.0 µm; Percentage by volume of total inorganic filler: approx. 50%; Percentage by weight of total inorganic filler: approx. 68%. Indications for use include: permanent cementation for all types of root canal posts, core build-ups and permanent cementation of crowns, bridges, inlays, onlays (ceramic, metal and composite) (Coltene, Switzerland, 2016).

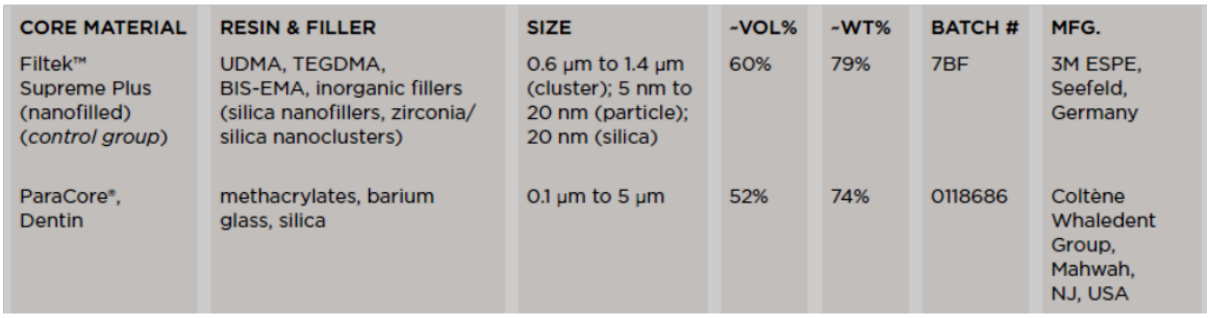
CoreXflow consists of two-components, base and catalyst, which when mixed forms a dual-cured, highly filled, composite resin core build-up. The material contains UDMA, Di & tri-functional methacrylates and 69% fillers by weight. Indications for use include: vital or non vital tooth core build-up (replacement of existing restorations and/or lost tooth structure) as a base prior to fabricating an indirect restoration and cementation of endodontic fiber-posts (Dentsply, USA, 2016).

Filtek Supreme XTE is a visible light cured composite. The fillers are a combination of non-agglomerated/non-aggregated 20 nm silica filler, non-agglomerated/non-aggregated 4 to 11 nm zirconia filler, and aggregated zirconia/silica cluster filler (comprised of 20 nm silica and 4 to 11 nm zirconia particles). The material is classified as a nano-composite. The Dentin, Enamel and Body (DEB) shades have an average cluster particle size of 0.6 to 10 microns. The Translucent (T) shades have an average cluster particle size of 0.6 to 20 microns. The inorganic filler loading is about 72.5% by weight (55.6% by volume) for the translucent shades and 78.5% by weight (63.3% by volume) for all other shades. Indications for use include: direct anterior and posterior restorations (including occlusal surfaces), core build-ups, splinting and indirect restorations (including inlays, onlays and veneers) (3M ESPE, 2010).

SDR Flow is a posterior Bulk fill flowable composite that is one-component, fluoride-containing, visible light-cured radio-opaque resin composite restorative material. The Inorganic fillers are 68% by weight and 45% by volume. Indications for use include: base in cavity class l and ll direct restorations, liner under direct restorative materials-class ll box liner, pit and fissure sealant, conservative class l restorations and core Build-ups (Dentsply, USA, 2011).

The present study revealed a significant difference in flexural strength between the materials specifically designed for core build-up material namely ParaCore and CoreXflow and the 2 conventional composites namely Filtek Supreme XTE and SDR ($p<0.05$). ParaCore had the higher mean flexural strength. Comparing the composition of the materials it is evident that there is a difference in the size and volume of their inorganic fillers (Table 13). The higher flexural strength values for ParaCore could be attributed to the smaller filler size; 0.1-.5μm compared to Filtek Supreme XTE 0.6-1.4μm clusters. This according to Omaghi's study means that composites with smaller fillers would be superior under the conditions of lower cyclic stress, such as normal chewing because they have a greater fatigue resistance (Omaghi, *et al.*, 2014).

Table 13: Composite Core materials: Composition (Passos, et al., 2013).



CORE MATERIAL	RESIN & FILLER	SIZE	~VOL%	~WT%	BATCH #	MFG.
Filtek™ Supreme Plus (nanofilled) (*control group*)	UDMA, TEGDMA, BIS-EMA, inorganic fillers (silica nanofillers, zirconia/ silica nanoclusters)	0.6 μm to 1.4 μm (cluster); 5 nm to 20 nm (particle); 20 nm (silica)	60%	79%	7BF	3M ESPE, Seefeld, Germany
ParaCore®, Dentin	methacrylates, barium glass, silica	0.1 μm to 5 μm	52%	74%	0118686	Coltène Whaledent Group, Mahwah, NJ, USA

Passos and colleagues (2013) also found that when comparing the fracture toughness (FT) of Filtek Supreme Plus and ParaCore, no significant difference was found. The FT was 1.53 MPa and 1.63 MPa for Filtek Supreme and Paracore respectively. The Diametral tensile strength of the two materials were also similar; Filtek Supreme: 40.5 MPa and ParaCore: 41.7 MPa; hence no significant difference (Passos, *et al.*, 2013). The previous study results could be attributed to the similarity in filler loading by weight.

ParaCore has also shown improved physical properties when compared to silorane-based material (Filtek TM 90). The silorane-based material (Filtek TM P90) showed the highest flexural strength, but other mechanical properties (compressive and tensile strength) were inferior to dual cure composite materials (LuxaCore and ParaCore) with nanofillers (Agrawal & Mala, 2014). ParaCore composite resin material showed excellent physical properties because it is reinforced with glass fibers; it is a dual cure material that will ensure complete cure, thereby improve the strength of the material. The macroscopic size of the unidirectional fiber bundles used in fiber reinforces the resins and improves their mechanical properties.

The presence of fibers affects the fracture process that results in interrupting crack growth progression and thus enhances the fracture toughness of the fiber-reinforced composite material (Coltene, Switzerland, 2016).

The mean flexural strength (FS) was highest for CoreXflow followed by ParaCore. The presence of urethane dimethacrylate (UDMA) in the resin matrix of CoreXflow may contribute to the superior mechanical properties (Zankuli, *et al.*, 2015). This was also supported by a previous study that reported that replacing bisphenol A-glycidyl methacrylate with UDMA resulted in improved flexural and tensile strength of resin composites (Tolosa, et al., 2005). When compared to Bright Flow and Grandio Core, Core Xflow had significantly higher compressive strength because of its higher filler loading. The filler loading of Grandio Core and CoreXflow was higher than the other materials; and the fatigue strength of Grandio Core was significantly higher than CoreXflow due to the filler loading. Grandio Core has a filler weight loading of 77% compared to CoreXflow's 69 wt% (Zankuli, *et al.*, 2015).

The bulk fill flowable composite material Surefil® SDR (Smart Dentin Replacement)(Denstply, USA) flow contains a polymerization modulator, chemically embedded in the center of the polymerizable resin backbone of the SDR™monomer, to lower polymerization shrinkage. De Biasi et al. (2010) investigated micro-hardness and raised concerns about its practical use due to its low Vickers hardness (HV). This was also confirmed by Ilie et al. (2011a) where Surefil® SDR™ flow showed the lowest surface hardness when compared to other commonly used RBCs (EsthetX Flow, Filtek Supreme Plus Flow, EsthetX Plus, Filtek Silorane, and Filtek Supreme Plus). A recent study also found that the mechanical properties of the bulk-fill low viscosity flowable composites were mostly lower compared with the conventional high viscosity material, and, at best, comparable to the conventional flowable composite. Given the lower mechanical properties of most bulk-fill materials compared to a highly filled nano-hybrid composite, their use for restorations under high occlusal load is subject to caution. (Leprince, *et al.*, 2014).

The major disadvantage of composite resins is that the materials undergo polymerization shrinkage, resulting in the release of stresses, which ultimately affects the materials shear bond strength, volumetric stability and its mechanical properties (Oliva & Lowe, 1987). Bond strength values are gross assessing tools for evaluating the efficacy of bonding restorative materials to dentin. Of the various tests the shear bond strength is less technique sensitive to perform, highlighting the strength of the bonded interface. This study compared the SBS of four composite resin core build-up materials with respective dentine bonding adhesives provided and recommended by the manufacturer, to achieve the maximum effect of bonding procedure (Table 5).

The present study was done in-vitro, as the clinical functions and characteristics of dental materials are difficult to evaluate under in-vivo conditions, and clinical trials cannot estimate mechanical properties of restored teeth (Petronijevic, *et al.*, 2012). Whereas in-vitro tests gives the possibility to evaluate mechanical properties of restored teeth and is considered as a predictor of the possible clinical performance of the material (Cohen, *et al.*, 1997).

The coronal surface was used to evaluate SBS as previous studies have shown that a reduction in bond strength occurs when resin composites are bonded to deep dentin (Srinivasulu, *et al.*, 2012) which can be attributed to the complexities in the structure of deep dentin, such as increase in the number of tubules and their diameters with much lesser intertubular dentin matrix as compared to superficial dentin (Tagami & Pashley, 1990).

This study made use of healthy incisor teeth with intact dentin because it was previously shown that restored incisors with carious-affected dentin may lower fracture resistance than healthy incisor teeth (Erhardt, *et al.*, 2008). Yoshiyama et al (2002) have found that many specimens of resin—bonded caries-affected dentin failed cohesively in dentine. This did not occur in normal dentine, where the bonds failed adhesively (Yoshiyama, *et al.*, 2002). This was confirmed by Markovic and colleagues (2011) that found that caries affects the bond strength of the restorative material and dentine and leads to lower mechanical properties of the restored teeth.

In the present study the mean Shear Bond Strength (SBS) was highest for SDR Surefill followed by ParaCore. The Mean SBS values for SDR Surefill, ParaCore, Filtek Supreme XTE and CoreXflow, obtained were 147.6 N, 142 N, 137 N, 119.2 N respectively. However no statistical significance difference in shear bond strength were observed between all materials tested including a good bond between all cements bonded to tooth structure (Dunn-Sadak; $p>0.05$).

Shear bond strength is greatly affected by a material's degree of polymerization shrinkage which influences its adhesion to dentine. The amount of intact dentine also affects the bond strength of the material (Markovic, *et al.*, 2011). Polymerization shrinkage is related to the organic and inorganic content of the composite resins. Flowable composites generally contain more organic matrix in order to gain increased flow. Thus, they have greater shrinkage compared to hybrid composites, which have less organic matrix (Correa, *et al.*, 2010). All materials were used in increments of 2 mm to counter act any shrinkage that may occur.

The fluidity of flowable composites allows it to act as shock absorbers, which counter acts any polymerization stresses (Dietschie, et al., 2003; Li, *et al.*, 2006). The bulk fill material Surefil® SDR™ flow contains a polymerization modulator, chemically embedded in the center of the polymerizable resin backbone of the SDR™monomer, to lower polymerization shrinkage. Investigations on RBCs with SDR™ technology showed significant lower shrinkage stress values (Burgess & Cakir, 2010) not only when compared to regular flowable RBCs, but also to nano- and hybrid RBCs or even to silorane-based composites (Ilie & Hickel, 2011a).

CoreXflow is also a flowable composite that has proven to be successful when used with its XP bonding system around fiber reinforced posts. The material demonstrated good bond strength and minimal nanoleakage (Mazzoni, *et al.*, 2009). However the literature fails to produce any studies on the shear bond strength of CoreXflow without the use of a post.

Various dual-cured resin composite build-up restoratives that combine the advantages of light curing and self curing mechanisms have been introduced, with the rationale to develop a material capable of reaching higher degree of polymerization in either the presence or absence of light, and overcome the limitations of reduced interlayer strength (Kournetas, et al., 2011). In a recent study comparing the shear bond strength of 3 dual-cure core build-up materials; Multi-Core dual-cure resin based core build-up material showed the highest mean SBS as compared to FluoroCore and ParaCore. SBS was not negatively affected by thermocycling (Jain, *et al.*, 2015), hence the studied specimens were not thermocycled prior to shear bond tests.

Both the ParaCore and Filtek adhesives (Table 5) contain ethanol as an organic solvent in the bonding agent. A previous study has shown that ethanol does not chase water due to its high boiling temperature and less vapour pressure as opposed to acetone adhesives which could efficiently remove surface water and increase vapour pressure (Nair, *et al.*, 2014). Thus this can adversely affect the material's shear bond strength.

All the materials showed good adhesion to the tooth structure. ParaCore displayed the most adhesive failures at 75% followed by Filtek at 70%. This could be possibly be due to the presence of ethanol contain in their adhesive composition. SDR displayed the highest cohesive failures at 60% followed by CoreXflow at 45 %. These results could be due to both materials making use of XP Bond as an adhesive. Which have shown to display good bond strength and minimal nanoleakage (Mazzoni, *et al.*, 2009).

CHAPTER 6

Conclusions and recommendations

6.1. Conclusions

In the present study the composite core materials specifically designed as core build up materials displayed a greater flexural strength compared to the conventional restorative composites used as core materials. A significant difference was found in the flexural strength of these materials. The physical properties of composites are greatly enhanced by alterations in their filler size and distribution of the filler. The filler component has a great influence on the dental composite's ability to resist crack initiation and propagation, as well as its response to abrasion and contact loading leading to wear. The smaller filler sizes and greater filler loading of CoreXflow and ParaCore have shown to increase the flexural strength of these materials thus making them more superior for the use as core build-up material compared to the conventional restorative composites.

No significant difference was found when the shear bond strength of these materials was compared. This could be attributed to the composition of the core materials as well as the composition of the various adhesive systems used. There was good adhesion of all the materials to the tooth structure.

6.2. Recommendations

Various conventional restorative composite materials are being indicated as core materials however these materials physical properties might not be adequate for use as core-build up materials. When selecting a core material is important to have the knowledge of the composition of the material as well as the adhesive systems recommended by the manufacturer.

An ideal core build-up material should have physical properties similar to that of tooth structure, as a restored tooth tends to transfer stress differently than an intact tooth. Flexural and shear bond strengths of core materials are thought to be important because cores usually replace a large bulk of tooth structure and must resist multidirectional masticatory forces for many years. The core material should have flexural strength to prevent core dislodgement during function. Shear bond strength of a core material is a crucial property that will determine the ultimate suitability of a material to be advocated clinically. Several dental materials have been used for core build-up procedures although not specifically designed for core build-up. The knowledge of the material's physical properties will ultimately determine their selection as core build-up material. Even though a material is indicated as core build-up material does not necessarily mean that the material's strength is adequate to resist forces during function or mastication.

6.3. Limitations of study

The present study was done in-vitro, as the clinical functions and characteristics of dental materials are difficult to evaluate under in-vivo conditions, and clinical trials cannot estimate mechanical properties of restored teeth. In-vitro tests give the possibility to evaluate mechanical properties of restored teeth and could be considered as a predictor of the possible clinical performance of the material. Clinically other factors such as moisture control and masticatory load can affect the results of the current study.

CHAPTER 7

References

Agrawal, A. & Mala, K., 2014. An in vitro comparative evaluation of physical properties of four different types of core materials. *Journal of Conservative dentistry*, 17(3), pp. 230-233.

Alrahlah, A., Silikas, N. & Watts, D., 2014. "Post-cure depth of cure of bulk-fill dental resin composites". *Dental Materials*, Volume 30, pp. 149-154.

Anusavice, K., Shen, C. & Rawls, H., 2013. *Phillips's science of dental materials.* 12 ed. St. Louis: Elsevier.

Armstrong, S., Geraldeli, S. & Rodigo, M., 2010. Adhesion to tooth structure: A critical review of "micro" and "macro" bond strength test methods. *Dental Materials*, Volume 26, pp. e50-e62.

Bayindir, Y., 2007. Comparison of diametral tensile, flexural, and compressive strengths of five core build-up materials. *Atatürk Üniv. Di*, pp. 18-28.

Bayne, S., Heymann, H. & Swift, E., 1994. Update on dental composite restorations. *Journal of American Dental Association*, Volume 125, pp. 687-701.

Bayne, S., Thompson, J. & Swift, E., 1998. A characterization of first-generation flowable composites. *J Am Dent Assoc*, 129(5), pp. 567-77.

Bonilla, E., Mardirossian, G. & Caputo, A., 2000. Fracture toughness of various core build-up materials. *Journal of prosthodontics*, Volume 9, pp. 14-18.

Bonilla, E., Yashar, M. & Caputo, A., 2003. Fracture toughness of nine flowable composites.. *The journal of prosthetic dentistry*, Volume 89, pp. 216-267.

Burgess, J. & Cakir, D., 2010. Comparative properties of low-shirnkage composite resins. *Compend Cont Educ Dent*, Volume 31, pp. 10-15.

Burke, F., Hussain, A. & Nolan, L., 2008. Methods uses in dentine bonding tests: a analysis of 102 investigations on bond strength. *European Journal of Prosthodontic Restorative Dentistry*, Volume 16, pp. 158-65.

Celik, C., Ozgunaltay, G. & Attar, N., 2007. Clinical evaluation of flowable resins in non-carious cervical lesions: two-year results. *Operative Dentistry*, Volume 32, pp. 313-321.

Chen, M., 2010. Update on dental naocomposites. *Journal of Dental Restoratives*, Volume 89, pp. 549-60.

Choi, K., Ferracane, J. & Hilton, T., 2000. Properties of packable dental composites. *Journal of Esthetic Dentistry*, Volume 12, pp. 216-26.

Christensen, G., 2012. Advantages and challenges of bulk-fill resins. *Clinical Report,* Volume 5, pp. 1-2.

Christensen, R., 2000. Building up tooth preperations for full crowns-2000. *Journal of American Dental Association,* Volume 131, pp. 205-506.

Chung, C., Kim, J. & Kim, K., 2002. Development of a new photocurable composite resin with reduced curing shrinkage. *Dental Materials,* Volume 18, pp. 174-178.

Chutinan, S., Platt, J. & Cochran, M., 2004. Volumetric dimensional change of six core materials. *Dental Materials,* Volume 20, pp. 345-351.

Cobb, D., MacCregor, K. & Vargas, M., 2000. The physical properties of packable and conventional posterior resin-based composites: a comparison. *Jouranl of American Dental Association,* Volume 131, pp. 1610-1615.

Cohen, B., Pagnillo, M. & Deutsch, A., 1997. Fracture atrength of three core restorative materials supported with or without a prefabricated split-shank post. *Journal of Prosthetic dentistry,* Volume 78, pp. 560-5.

Coltene., 2016. Coltene/Whaledent Technical Specifications. http://nam.coltene.com

Combe, E., Shaglouf, A. & Watts, D., 1999. Mechanical properties of direct core materials. *Dental Materials,* Volume 15, pp. 158-165.

Condon, J. & Ferracane, J., 1997. In vitro wear of composite with varried cure, filler level and filler treatment. *J Dent Res,* Volume 76, pp. 1405-1411.

Correa, M., Henn, S. & Marimon, J., 2010. Factors influencing the microhardness of a microhybrid composite. *General Dentistry,* Volume 58, pp. e94-e98.

Craig, R. & Powers, J., 2002. *Restorative Dental Materials.* 11 ed. St. Louis: Mosby Inc.

Curtis, A., Palin, W. & Fleming, G., 2009. The mechanical properties of nanofilled resin-based composites: the impact of dry and wet cyclic pre-loading on bi-axial flexural strength. *Dental materials,* Volume 25, pp. 188-97.

Czasch, P. & Ilie, N., 2013. In vitro comparison of mechenical properties and degree of cure of bulk fill composites. *Clinical Oral Investigations,* Volume 17, pp. 227-235.

Davidson, C., de Gee, A. & Feilzer, A., 1984. The competition between the composite-dentine bond strength anthe polymerization contraction stress. *Journal of Dental Restorations,* Volume 63, pp. 1396-1399.

de Biasi, M., Calvi, R. & Sossi, D., 2010. Microharness of a new flowable composite liner for posterior restorations. *Dental Materials,* Volume 26, pp. e25-e25.

Dentsply., 2011. Dentsply Technical Specifications. http://www.dentsply.com

Dentsply., 2016. Dentsply Technical Specifications. http://www.dentsply.com

Dietschie, D., Olsburgh, S. & Davidon, C., 2003. In vitro evaluation of marginal and internal adaptation after occlusal stressing of class II composite restoations with different resinous bases. *European Jouranl of oral science,* Volume 111, pp. 73-80.

Dogon, L., 1990. Present and future value of dental composite materials and sealant. *Int J Technol,* Volume 6, pp. 369-377.

El-Nawawy, M., Koaitim, L. & Abouelatta, O., 2012. Depth of cure and microhardness of nanofilled, packable and hybrid composite rsins. *American journal of biomedical engineering,* Volume 2, pp. 214-250.

El-Safty, S., Silikas, N. & Watts, D., 2012. Creep deformation of rstorative resin-composites intended for bulk-fill placement. *Dental Materials,* Volume 28, pp. 928-935.

Emami, N., Soderholm, K. & Berglund, L., 2003. Effect of light power density variations on bulk curing properties of dental composites. *J Dent,* Volume 31, pp. 189-196.

Erhardt, M., Toledano, R. & Osono, L., 2008. Histomorphological characterization and bond strength evaluation of carries affected dentin/resin interfaces: Effects of long term water exposure. *Dental Materials,* Volume 24, pp. 786-796.

Ernst, C., Bradenbusch, M. & Meuer, G., 2006. Two-year clinical performance of a naofiller vs a fine-particle hybrid resin compoiste. *Clinical Oral Investigations,* Volume 10, pp. 119-25.

Ernst, C., Canbank, K. & Akskogan, K., 2003. Two-year clinical performance of a packable posterior composite with and without a flowable composite. *Clinical Oral Inestigations,* Volume 7, pp. 123-128.

Estafan, D. & Agosta, C., 2003. Eliminating microleakage from the composite resin system. *General Dentistry,* Volume 51, pp. 506-509.

Feilzer, A., de Gee, A. & Davidson, D., 1987. Setting stress in composite resin in relation to configuration of the restoration. *Journal of Dental Research,* Volume 66, pp. 1636-1639.

Ferracane, J., 2011. "Resin composite-state of the art". *Dental materials,* 27(1), pp. 29-38.

Ferracane, J., Pheifer, C. & Hilton, T., 2014. Microstructural features of current Resin composite materials. *Current Oral Health Reports,* Volume 1, pp. 205-212.

Finan, L., Palin, W. & Moskwa, N., 2013. The inflence of irradiation potential on the degree of conversion and mechanical properties of two bulk-fill flowable RBC base materials. *Dental Materials,* 29(8), pp. 906-912.

Fortin, D. & Vargas, M., 2000. The spectrum of composites: new technology and materials. *Journal of American Dental Association,* Volume 131, pp. 26S-30S.

Gallato, A., Angnes, G. & Reis, A., 2005. Long-term monitoring of microleakage of different amalgams with different liners. *The Journal of Prosthetic Dentistry,* 93(6), pp. 571-576.

Garcia, A., Lozano, M. & Vila, J., 2006. Composite resins. A review of the materials and clinical indications. *Med Oral Patol Oral Cir Bucal,* 11(2), pp. 215-220.

Garcia, D., Yaman, P. & Dennison, J., 2014. Polymerization shrinkage and depth of cure of bulk fill flowable composite resins. *Operative Dentistry,* 39(4), pp. 441-448.

Han, L., Ishizaki, H. & Fukushima, M., 2009. Morphological analysis of flowable resins after long-term storage or surface polishing with a mini-brush. *Dental Materials,* Volume 28, pp. 277-284.

Ilie, N., Bucuta, S. & Draenert, M., 2013. Bulk-fill resin-based composites: An in vitro assessment of their mechanical performance. *Operative dentistry,* Volume 38, pp. 618-628.

Ilie, N. & Hickel, R., 2009a. Investigations on mechanical behavior of dental composites. *Clinical Oral Investigations,* Volume 13, pp. 427-38.

Ilie, N. & Hickel, R., 2009b. Macro-, micro- and nano-mechanical investiagtions on silorane and methacrylate-based composites. *Dental Materials,* Volume 25, pp. 810-9.

Ilie, N. & Hickel, R., 2011a. Investigations on a methacrylate-based flowable composite based on SDR technology. *Dental Materials,* Volume 27, pp. 384-355.

Ilie, N. & Hickel, R., 2011b. Resin composite restorative materials. *Australian dentall journal,* Volume 56, pp. 59-66.

Jain, G., Narad, A. & Boruah, L., 2015. Comparative evaluation of shear bond strength of three resin dual-cure core build-up materials: An in-vitro study. *Journal of conservative dentistry,* 18(14), pp. 337-341.

Kanchanavasita, W., Anstice, H. & Peatson, G., 1998. Long-term flexural strength of resin-modified glass-ionomer cements. *Biomaterial,* Volume 19, pp. 1703-1713.

Klein, F., Keller, A. & Stawhle, H., 2002. Proximal contact formation with different restorative materials and techniques. *American Journal of Dentistry,* Volume 15, pp. 232-235.

Kournetas, N., Tzoutzas, I. & Eliades, G., 2011. Monomer conversion in dual-cured core buildup materials. *Operative Dentistry,* Volume 36, pp. 92-7.

Kramer, N., Reinelt, C. & Richter, G., 2009. Nanohybrid vs. fine particle composite in class ll cavities: clinical resu;ts and margin analysis after four years. *Dental Materials,* Volume 25, pp. 750-9.

Land, M. & Rosenstiel, S., 2006. *Contemporary Fixed Prostodontics.* 4 ed. Elsevier: Mosby.

Leinfelder, K., Bayne, S. & Swift, E., 1999. "Packable composites: Overview of technical considerations". *Journal of Esthetic and Restorative Dentistry,* Volume 5, pp. 234-249.

Leloup, G., D'Hoore, W. & Bouter, D., 2001. Meta-analytical review of factors invilved in dentin adherence. *Journal of Dental Restoratives*, Volume 80, pp. 1605-14.

Leprince, J., Palin, W. & Vanacker, J., 2014. Physico-mechanical characteristics of commercially available bulk-fill composites. *Journal of dentistry*, Volume 42, pp. 993-1000.

Li, Q., Jepsen, S. & Albers, H., 2006. Flowable materials as a intermediate layer could improve the marginal and internal adaptation of composite restorations in Class V cavities. *Dental Material*, Volume 22, pp. 250-257.

Loguercio, A., Zago, C. & Leal, K., 2005. One-year clinical evaluation of a flowable resin liner associated with a microhybrid resin in noncarious cervical lesions. *Clinical Oral Investigations*, Volume 9, pp. 18-20.

Lopes, L., Cefaly, D. & Fanco, E., 2003. Clinical evaluation of two "packable" posterior composite resins: two year results. *Clinical Oral Investigations*, Volume 7, pp. 123-128.

Lutz, F. & Phillips, R., 1983. A classification and evaluation of composite resin systems. *Journal of Prosthetic Dentistry*, Volume 50, pp. 480-488.

3M ESPE., 2010. 3M ESPE Technical Product Profile. multimedia.3m.com

Manhart, J., Kunzelmann, K. & Chen, H., 2000. Mechanical properties and wear behavior of light-cured packable composite resins. *Dental Materials*, Volume 16, pp. 33-40.

Markovic, D., Petronijevic, B. & Blazic, L., 2011. Bond strength comparison of three core build-up material used to restore maxillary incisor teeth. *Contemporary materials*, II(1), pp. 62-68.

Masouras, K., Silikas, N. & Watts, D., 2008. Correlation of filler content and elastic properties of resin composites. *Dental Materials*, Volume 24, pp. 932-939.

Mazzoni, A., Marchesi, G. & Cadenaro, M., 2009. Push-out stress for fibre posts luted using different adhesive stratergies. *European journal of oral science*, Volume 117, pp. 447-453.

Mc Cabe, J., 1998. Resin-modified glass ionomer cements. *Biomaterials*, Volume 19, pp. 521-527.

Meiers, J. & Turner, E., 1998. Microleakage of dentin/amalgam alloy bonding agents: results after 1 year. *Operative Dentistry*, Volume 23, pp. 30-5.

Nair, M., Kumur, S. & Chakravarthy, Y., 2014. Comparative evaluation of the bonding eficacy of sixth and seventh generation bonding agents: An in-vitro study. *J Conservative Dent*, Volume 17, pp. 27-30.

Nomoto, R., Asada, M. & Mc Cabe, J., 2006. Light exposure required for optimum conversion of light activated resin systems. *Dental Material*, Volume 22, pp. 1135-1142.

Nujella, B., Choudary, M. & Reddy, S., 2012. Comparison of shear bond strength of aesthetic restorative materials. *Contemporary Clinical Dentistry,* 3(1), p. 22.

Oliva, R. & Lowe, J., 1987. Dimensional stability of silver amalgam and composite used as core material. *Journal of prosthetic dentistry,* Volume 57, pp. 554-9.

Omaghi, B., Meier, M. & Rosa, V., 2012. Subcritical crack growth and in votro lifetime prediction of resin composites with different filler distribution. *Dental Materials,* 28(9), pp. 985-95.

Omaghi, B., Meier, M. & Rosa, V., 2014. Fracture toughness and cyclic fatigue resistance of resin composites with different filler size distributions. *Dental Materials,* 30(7), pp. 742-51.

Ozel, E., Korkmaz, Y. & Attar, N., 2008. Effect of one-step polishing systems on surface roughness of different flowable restorative materials. *Dental Materials,* Volume 27, pp. 755-764.

Passos, S., Freitas, A. & Jumaily, S., 2013. Comparison of mevhanical properties of five commercial dental core build-up materials. *Compendium,* 34(1), pp. 62-68.

Perdigao, J., Geraldeli, S. & Lee, K., 2004. Push-out bond strengths of tooth-colored posts bonded with defferent adhesive systems. *American journal of dentistry,* Volume 17, pp. 422-426.

Petronijevic, B., Markovic, D. & Sarcev, I., 2012. Fracture resistance of restored maxillary premolars. *Contemporarary Materials,* III(2), pp. 219-225.

Peumanns, M., Merbeek, B. & Asscherick, K., 2001. Do condensable composites help to acheive better proximal contacts. *Dent Materials,* Volume 17, pp. 533-541.

Puckett, B., Fitchie, J. & Chaterjee, K., 2007. Direct composite restorative materials. *Dental Clinics of North America,* Volume 51, pp. 659-675.

Ravi, R., Alla, R. & Shammas, M., 2013. Dental Composites-A Versatile Restorative Material: An Overview. *Indian Journal of Dental science,* Volume 5, pp. 11-115.

Saygili, G. & Sahmali, S., 2002. Comparative study of the physical properties of core materials. *International Journal Periodontics Restorative Dentistry,* Volume 22, pp. 355-363.

Shilingburg, H., Hobo, S. & Whitsett, L., 1997. *Fundamentals of Fixed Prosthodontics.* 3 ed. St. Louis: Quint Publishing Co.

Srinivasulu, S., Vidhya, S. & Sujatha, M., 2012. Shear bond strength of composite to deep dentine after treatment with two different collogen cross-linking agents at varying time intervals. *Operative Dent,* Volume 37, pp. 485-91.

Sturdevant, J., Bayne, S. & Wilder, A., 1993. 3-Year clinicsal study of a failed condensable posterior composite. *Journal of Dental Restoratives,* Volume 72, p. 380.

Tagami, J. & Pashley, D., 1990. Correlation among dentin depth, permeability, and bond strength of adhesive systems. *Dental Materials,* Volume 6, pp. 45-50.

Thomsen, K. & Peutzfeldt, A., 2007. Resin Composites: strength pf the bond to dentine versus mechanical properties. *Clinical Oral Investigations,* Volume 11, pp. 45-9.

Tolosa, M., Paulillo, L. & Giannini, M., 2005. Influence of composite restorative materials and light-curing units on dimetrical tensile strength. *Brazilian Oral Research,* 19(2), pp. 123-126.

Van Meerbeek, B., Peumanns, M. & a., P., 2010. Relationship between bond strength test and clinical outcomes. *Dental Materials,* Volume 26, pp. e100-e121.

Van Noort, R., 2002. *Introduction to dental materials.* 2 ed. St. Louis: Mosby Inc.

Walmsley, A., Walsh, T. & Burke, F., 2002. *Restoration of teeth (Complex Restorations).* Churchill: Livingstone.

Wassell, R., Smart, E. & George, G., 2002. Crowns and extra coronal restorations: Cores for teeth with vital pulps. *British dental Journal,* Volume 192, pp. 499-509.

Willems, G., Lambrechts, P. & Bream, M., 1992. A classification of dental composites according to their morphological and mechanical charcteristics. *Dental Materials,* Volume 8, pp. 310-319.

Xie, H., Zhang, F. & Wu, Y., 2008. Dentine bone strength and microleakage oif flowable composite, compomer and glass ionomer cement. *Australian Dental Journal,* Volume 53, pp. 325-331.

Yap, A., Low, J. & Ong, L., 2000. Effect of food-stimulating liquids on surface characteristics of composite and poly-acid composite restoratives. *Operative Dentistry,* Volume 25, pp. 170-176.

Yoshiyama, F., Tay, R. & Doi, J., 2002. Bonding of self-etch and total-etch adhesives to carious dentin. *Journal of dental reseach,* Volume 81, pp. 556-560.

Zankuli, M., Silikas, N. & Devlon, H., 2015. The effect of cyclic-loading on the compressive strength of core build-up materials. *Journal of prosthodontics,* Volume 24, pp. 549-552.

Zimmerli, B., Strud, M. & Jeger, F., 2010. Composite Materials: composition, properties and cliniacal applications: A literature review. *Schweizer Monatsschrift fur Zahnmedizin,* 120(11), pp. 972-986.

Ziskind, D., Venezia, E. & Kreisman, I., 2003. Amalgam type, adhesive system, and storage period as influencing factors on microleakage of amalgam restorations. *Journal of Prosthetic Dentistry,* Volume 90, pp. 255-60.

Chapter 8

Appendix

Appendix 1: Patient Information Sheet

Oral & Dental Research Institute

Faculty of Dentistry and WHO Oral Health Collaborating Centre

University of the Western Cape

Cape Town

Patient Information Sheet to be given to the patient to take home

I, Dr Winifred Asia am a qualified dentist involved in research and training at the University of the Western Cape, Faculty of Dentistry.

I am doing research on how well new composite restorative materials adhere to tooth structure.

After the removal of your maxillary incisor tooth, they will be either discarded or given to the students to practice on. I wish to use your extracted teeth to be able to determine which restorative material has the greatest adhesion to the tooth structure in the laboratory.

Donating your tooth to the study is on a voluntary basis. Donating your tooth for this study or refusing to participate will not harm or prejudice you in any way. The tooth supplied to me will not have your name on it as well as I will not be able to identify you in any way. Upon completion of the study the teeth will be discarded or given to the students to practice on.

Participating in the study will definitely benefit future studies and will add to our existing pool of knowledge. All information will be kept strictly confidential.

Thanking you.

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Dr. Winifred Asia

Researcher

Oral & Dental Research Institute

Oral Health Centre Tygerberg

Contact details: Tel: (021) 937 3170

Mobile: 078 000 7239

I, (Patient name).., fully understand the information supplied to me by Dr Winifred Asia in this information sheet.

Signature: ....

Date: ....