

## CHAPTER II

### LITERATURE REVIEW

Direct bonding of orthodontic brackets has revolutionized orthodontics because of decreased gingival irritation, improved esthetics, the ability to maintain better oral hygiene, the elimination of band occupying interdental space, and the decreased chance of decalcification caused by leakage beneath bands. Many studies have been conducted to determine the bond strength of brackets to enamel. These included a comparison of adhesive systems (Eversoll and Moore, 1988; Fox et al., 1991; Joseph and Rossouw, 1990; Yamada et al., 1988), the uses of various types of bracket designs (Lopez, 1980), phosphoric acid concentrations (Cartensen, 1995; Legler et al., 1989), etching time (Barkmeier et al., 1985 and 1987) and the type of teeth (Sheen et al., 1993; Sheykholeslam and Bounocore, 1972).

Several factors affecting the bond strength are as follows:

1. Teeth
2. Brackets
3. Adhesive systems

#### 1. Teeth

##### **The structure of enamel**

Enamel consists of microscopic units called enamel prisms. The enamel prisms extend from the dentino-enamel junction to the outer surface at varying angles and this differs from tooth to tooth and from one surface to another within the same tooth. Each prism contains many small units called 'hydroxyapatite' crystals. Generally, the crystals dissolve faster if they are oriented in a perpendicular relationship to the tooth surface that will be etched.

The tooth surface is normally covered with a very thin layer of organic materials that form from the salivary constituents. This layer can be removed by thorough pumicing (Sheykholeslam and Brandt, 1977).

In each tooth, enamel surface plays major role to bond strength. Deciduous teeth had more frequently area of prismless enamel than in permanent teeth. Prismless zones might have negatively influence to the retention of resin. In order to remove such layers, prolonged etching time or mechanical removal of surface enamel prior to etching has been recommended (Sheykholeslam and Bounocore, 1972).

Nordenvall et al. (1980) compared surface irregularity in the scanning electron microscope of 15 and 60 seconds of etching with a 37 percent phosphoric acid solution on enamel surfaces from deciduous, young and old permanent teeth. They found that in deciduous teeth, there was no different in surface irregularity between the etching periods. For young permanent teeth, 15 seconds of etching created more retention conditions than 60 seconds, but for old permanent teeth the reverse was found. There were great variations in the effect of acids on enamel surface, because the enamel surfaces of old permanent teeth had more different composition than that of newly erupted teeth due to wear and replacement of organic material by mineral during the maturation process.

Sheen et al. (1993) reported in their investigation that the bond strength of the older permanent teeth was greater than the bond strength of the younger teeth, regardless of etching time. The older teeth become harder, more resistance to decay and less permeable to fluid than the younger teeth. Thus, the enamel become harder with age and reinforced the tensile bond strength.

## **2. Brackets**

There are three types of orthodontic bonding bracket: plastic, ceramic, and metal brackets.

## **2.1 Plastic brackets**

Plastic brackets are made of polycarbonate and used mainly for esthetic reasons. Currently available plastic brackets are handicapped by a lack of strength to resist breakage, wire slot wear (which leads to loss of tooth control), distortion following water absorption, fracture, discoloration, the need of compatible bonding resins, and an inability to withstand the torquing force generated by rectangular wires (Reynolds, 1975).

## **2.2 Ceramic brackets**

Ceramic brackets made of aluminium oxide could combine the esthetics of plastic and reliability of metal brackets. However, ceramic brackets available at present are not optimal. They are bulky. Their color is not satisfactory. They have the excessive bond strength. They do not bond upon pressure like a thin steel base and debonding must be careful. They have also been found to produce wear of enamel surfaces on opposing teeth (Douglass, 1989).

## **2.3 Metal brackets**

Although not as esthetically pleasing as plastic brackets, small metal brackets are an improvement over bands. Most clinicians prefer the metal brackets for routine applications (Graber and Swain, 1985).

Metal bases have not been satisfactorily chemically bonded to the adhesive. All base designs rely on mechanical retention. Perforations in the bracket base, wire mesh, small spherical photo-etched undercuts, undercut channels and sintered metal particles have been used to obtain the necessary mechanical retention.

Several authors have suggested that microscopic features of the bracket base, particularly of mesh designs, may increase or decrease the effectiveness of mechanical interlocking with the adhesives. These features include rough or smooth wires, mesh defects, mesh size, wire diameter, weld spots and sharp line angles on undercut channels.

Reynolds and von Fraunhofer (1976) tested tensile bond strengths with various size mesh bases and found that the coarser mesh bases gave significantly greater bond strength with all the adhesives tested.

Zachrisson and Brobakken (1978) stated that foil-mesh bracket base gave stronger bonds, retained less plaque and provided a smooth hygienic oral surface which appeared more esthetic than the perforated bases.

Lopez (1980) tested a large number of brackets and found that the bond strength was independent of the area and mesh size of the bases.

Maijer and Smith (1981) indicated that a fine mesh bracket base of the woven mesh type (Ormco, Rocky Mountain) gave superior shear bond strength.

Smith and Reynolds (1991) showed that the fine mesh base gave higher mean tensile bond strength compared with the coarse mesh and both mesh base showed greater bond strength compared to an undercut base.

### 3. Adhesive systems

#### 3.1 Principles of adhesion

##### 3.1.1. Surface properties and bonding

The surfaces which are required by adhesive bonding are microscopically or macroscopically rough. There is a danger of pockets of air being trapped between an adhesive and the surface, thus reducing the area of contact between them (Figure 1).

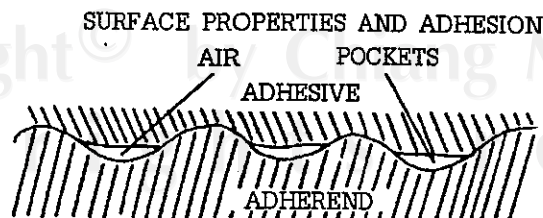


Figure 1 Air trapped between adhesive and adherend (From Combe, 1986).

However, if the rough surface is adequately wetted by the adhesive then this may increase the effective area of contact and hence improve the bond strength. For good adhesive bonding, the surfaces should be cleaned to remove debris and weakly-bound deposits (Combe, 1986).

Bonding is classified as physical, chemical, and/or mechanical bonding (Figure 2).

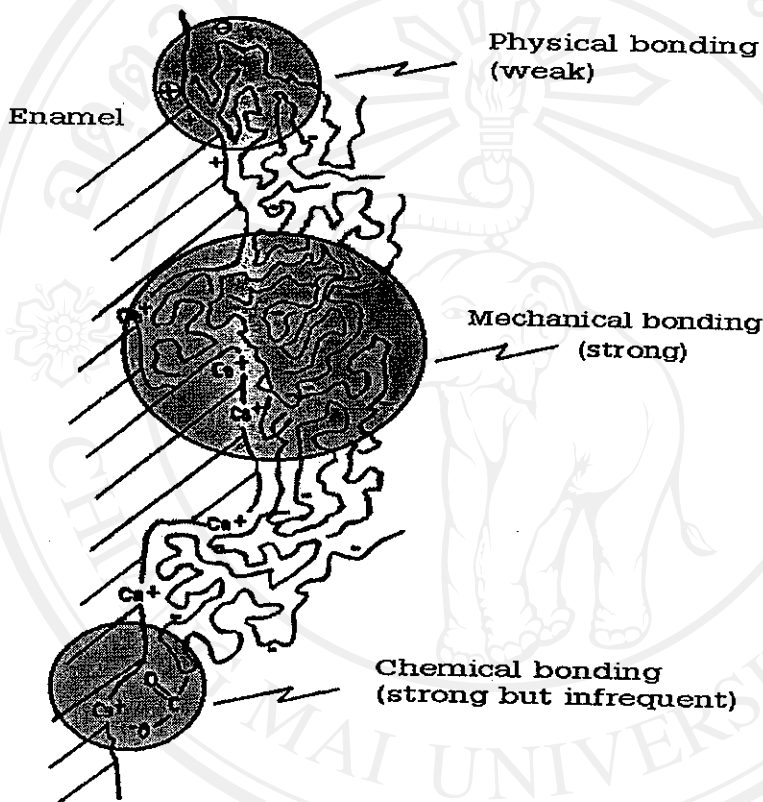


Figure 2 Schematic summary of contribution of physical, mechanical, and chemical bonding to interfacial adhesion (From Sturdevant, 1995).

Physical bonding involves van der Waals or other electrostatic interactions that are relatively weak (Figure 2). It may be the only type of bonding if surfaces are smooth and chemically dissimilar. Chemical bonding involves bonds between atoms which are formed across the interface from the adhesive to the adherent. Dissimilarity of materials limits the extension of material for bonding and the overall contribution to bond strength is normally quite low. Mechanical bonding is the result of undercuts and other irregularities

which produce interlocking of the materials. Almost dental adhesion is based primarily on mechanical bonding. Chemical bonding may occur as well, but generally makes only a small contribution to the overall bond strength (Sturdevant, 1995).

The common method for producing surface roughness is to grind or etch the surface. Grinding produces gross mechanical roughness. Acid etching or conditioning produces microscopic relief with undercuts on the surface to create an opportunity for mechanical bonding (Sturdevant, 1995).

### 3.1.2 Surface wetting

The ability of an adhesive to wet the surface of the adherend can be measured by the contact angle of a drop of liquid on the surface (Figure 3). Materials of low free surface energy will not be easily wetted. The surface energies of many surfaces may be increased by treatment in various ways. For example, dental enamel surfaces are treated by acid-etching which increases the surface energy.

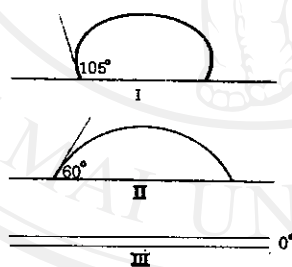


Figure 3 Surface wetting. I) contact angle  $105^\circ$ , II) contact angle  $60^\circ$ , III) contact angle  $0^\circ$  (From Combe, 1986).

The contact angle of a liquid on a smooth surface is an inverse measure of the degree of surface wetting of the surface (Figure 3). The contact angle depends on the surface energy of the solid and also on the surface tension of the liquid. Surface tension effects arise from the different balance of intermolecular attractions of molecules at a surface from those in the bulk of a material.

For low contact-angle values to be achieved, the surface tension of the fluid adhesive should ideally be lower than the critical surface tension of the solid.

### 3.1.3 Requirements for setting adhesive systems

Combe (1986) suggested that the requirements for setting adhesive systems were as follows:

- The adhesive must give good wetting of the adherend.
- The adhesive should have a suitable viscosity to enable it to flow readily over the surface of the adherend.
- The setting of the adhesive should occur without excessive dimensional changes that is little expansion or contraction.
- The thickness of the adhesive layer is important; too great a thickness can lead to poor bond strength (Figure 4).
- The strength of the set adhesive must be taken into consideration.

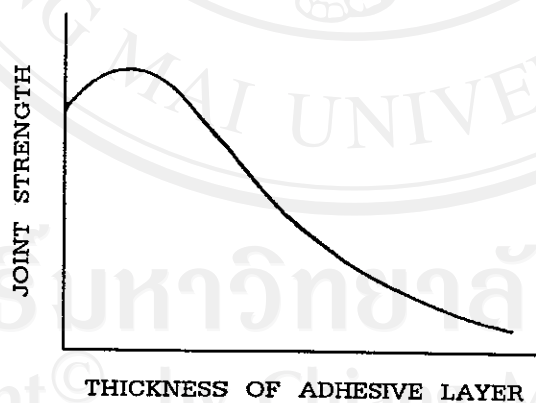


Figure 4 Effect of thickness of adhesive layer on bond strength (From Combe, 1986).

### **3.1.4 Thickness of adhesive**

Increasing the thickness of the adhesive layer was reported to give a weak joint due to the imperfections leading to stress concentrations, increased polymerization shrinkage, and easy deformation (Bounocore, 1963).

Alexandre et al. (1981) stated that the minimum thickness of the adhesive layer played an important role in obtaining maximum adhesion.

### **3.2 Method of obtaining bonding to enamel**

Many types of surface treatments have been tried experimentally in order to enhance bonding of material to enamel. These include the use of enzymes, chelating agents, acids and alkalines.

The acid etched techniques for modification of enamel are the great current importance. Acid etching changes the enamel surface from the low energy hydrophobic to a high energy hydrophilic surface, showing increased surface tension and wettability (Reynolds, 1975). Appropriate concentration of phosphoric and citric acids can remove 5 microns of the enamel surface and also selectively decalcify the enamel to a depth of 15-120 microns. Stronger acids do not give selective decalcification. Weaker acids react too slowly with enamel. Currently available acid etchants are usually 30-50% solution of phosphoric acid.

Combe (1986) suggested that acid etching may aid bonding to enamel by removing surface debris, producing pores in the surface into which resin penetrates to form tag-like extensions, increasing the free surface energy of the enamel and causing exposure of a greater surface area of enamel to the material.

#### **Etching of enamel surface**

The depth of etching or the amount of surface enamel lost during the etching procedure is dependent on the type of acid used, the acid concentration, the duration of etching, and the chemical composition of the enamel.



Numerous studies have shown that a reduction of acid concentration, pH of the acid and/or application time might not have adverse effects on the bonding process (Nordenvall et al., 1980; Barkmeier et al., 1985; Legler et al., 1989; Wasundhara and Pushpa, 1995). Now it seems to be a tendency to softer etching procedures (Sadowsky et al., 1990; Cartensen, 1995).

### **3.3 Types of adhesives**

The two most important groups of adhesives currently in use for direct bonding are polymers which may be classified as:

#### **3.3.1. Methacrylate resins**

These are based on self-curing acrylics. Methacrylate resins consist of methyl methacrylate monomer and ultrafine polymer powder, usually activated by the conventional tertiary amine benzoyl peroxide curing system. They occur in either filled or unfilled forms. Various modifications have been carried out to alter their properties for use as orthodontic adhesive. Methacrylate resins have a large coefficient of expansion, approximately ten times that the tooth substance and a volumetric contraction on curing of 6-10 percent. Although mouth temperatures can vary as 50° C, film thickness involved in bonding are not great and therefore the effects of these factors are minimized (Reynolds, 1975).

#### **3.3.2 Dimethacrylate resins**

Dimethacrylate resins are based on bisphenol-A-glycidyl dimethacrylate (BIS GMA) which was developed by Bowen. This forms a polymer which is extremely rigid with the characteristics of greater strength, lower water absorption and less shrinkage than the methacrylate resins. The increased bond strength of the dimethacrylate resins has led to their widespread application (Read, 1984).

The components of dimethacrylate resins may be listed as follows:

**a) Principal (higher molecular weight) monomers.**

Many orthodontic bonding adhesives are based on an aromatic dimethacrylate system, the monomer being the reaction product of bisphenol-A and glycidyl methacrylate, often called Bis-GMA or Bowen's resin. This highly viscous monomer can undergo free radical addition polymerization to give a rigid cross-linked polymer. A monomer similar to Bis-GMA, but with hydroxy groups, has also been used. Some products use alternative monomers which are described as urethane dimethacrylates (UDMA). The properties of orthodontic bonding adhesives based on these latter monomers are in general similar to those of materials containing Bis-GMA resin.

**b) Diluent (lower molecular weight) monomers.**

Other monomers are included in orthodontic bonding adhesives formulations to reduce the viscosity of the material to enable proper blending with inorganic constituents, and to facilitate clinical manipulation. The monomer of choice may be monofunctional monomers, such as methyl methacrylate; or difunctional monomers, such as ethylene glycol dimethacrylate and triethylene glycol dimethacrylate. Greater quantities of diluent monomer give lower viscosity and greater shrinkage on polymerization of adhesive material.

**c) Inorganic fillers.**

A wide variety of fillers has been used in dentistry. Early composite resins contained glass fibres and beads, synthetic calcium phosphates, fused silica. They contained fillers with particle size 10-40 microns. Current materials may contain lithium aluminosilicates, crystalline quartz, or barium aluminoborate silica glasses that fillers size is 0.05 micron.

Adhesives with the larger size particles contain typically 78% (by weight) of filler. However, products with microfine silica contain less inorganic filler. It is difficult to add larger quantities of microfine silica to a fluid monomer, since it acts as a thickening agent and confers thixotropy. It is usual

for microfine filler to be prepared in a matrix of cured resin, which is then ground, and incorporated in a difunctional monomer. In the present day, microfine adhesives contain 25-63% SiO<sub>2</sub> (by weight).

The incorporation of inorganic fillers has the following effects on a polymer:

- Improvement in mechanical properties such as compressive strength, modulus of elasticity and hardness.

- Reduction in coefficient of thermal expansion.

Li et al. (1985) suggested that the volume of filler had a greater effect on physical and mechanical properties than filler size.

In general, more highly filled cements bond better to metal bracket than less highly filled resin (Tavas and Watts, 1984).

#### **d) Polymerization inhibitors.**

An inhibitor is necessary for dimethacrylate monomers because monomers may polymerize on storage. Hydroquinone has been widely used as inhibitor, but it was responsible for causing discoloration of the material. So, the monomethyl ether of hydroquinone is now used.

#### **e) Initiator/activator components.**

Polymerization may be activated chemically by mixing two components, one component contains an initiator and the other contains an activator, or by an external ultraviolet or visible light source.

##### **Chemical activation**

Benzoyl peroxide initiator and tertiary amine activators, or sulphinic acid type initiators may be employed in chemically cured composite resins. These resins are presented in liquid/liquid, paste/liquid, powder/liquid or paste/paste systems.

Alexandre et al. (1981) studied the shear bond strength of three direct bonding orthodontic adhesives: Concise, Dyna Bond and Endur. One hundred and eight premolar teeth were divided into six groups and were loaded to

failure in an Instron® universal testing machine operated crosshead speed of 0.05 inches per minute. Duncan's multiple range test showed no statistical difference in shear bond strength among three materials. Endur and Dyna Bond failed at the bracket-adhesive interface while Concise failed at enamel-adhesive interface. They concluded that Concise bonded more strongly to enamel than to the bracket, whereas Endur and Dyna Bond bonded more strongly to the bracket than to enamel.

Bryant et al. (1987) determined the tensile bond strength of chemically cured orthodontic bonding systems (Concise, Lee Cleanse and Bond I, Lee Cleanse and Bond II, Instra-Bond and Protecto) with 5% phosphoric acid for 15 seconds and 15% phosphoric acid for 30 seconds and evaluated 15 minutes and 24 hours after specimens preparation. Twelve permanent canine teeth which stored in 70% ethyl alcohol were prepared for each system by wet grinding the buccal surface to achieve a flat surfaces. The specimens were loaded to failure in an Instron® universal testing machine operated at crosshead speed of 0.02 inches per minute. The 24-hour tensile bond strength of bonded brackets were not significantly different from the 15-minute bond strength except brackets bonded with Lee cleanse and Bond I to enamel surfaces etched with 15% phosphoric acid for 30 seconds. The tensile bond strength of brackets to enamel etched with 15% phosphoric acid for 30 seconds and with 5% phosphoric acid for 15 seconds were not significantly different except brackets bonded with Lee Cleanse and Bond II and tested 24 hours after bonding.

Eversoll and Moore (1988) studied shear and tensile strengths of five bonding adhesives: unfilled (Bracket Bond and Genie) and filled (Unite, Excel and Concise) adhesives. Few significant difference in shear and tensile strengths were found among the bonding adhesives. Unfilled bonding adhesives caused less enamel damage than filled adhesives and were indicated for clinical bonding of acrylic orthodontic appliance to enamel.

Delport and Grobler (1988) tested tensile bond strengths of three two-paste (Achieve, TP 1-to-1 and Concise) and four no-mix (Right-on, Attain,

System1+ and Mono-lok) orthodontic bonding resins. One hundred ninety-six extracted central incisors and canines were used to prepare 14 specimens for each systems. The results of this study suggested that all bonding resins were adequate retention of bonded orthodontic brackets in clinical situation and tensile bond strengths were not significantly different.

#### **U.V. activation**

The most commonly used initiator is benzoin methylether. At certain selected wavelengths within the ultraviolet range, this molecule is able to absorb radiation and undergo heterolytic decomposition to form free radicals. The polymerization reaction is initiated when the radical which is formed on activation reacts with a monomer molecule. The initiation reaction produces another active free radical species which is capable of further reaction. This is an addition reaction.

The use of ultraviolet activated materials has diminished greatly since the possible dangers of long term exposure to ultraviolet radiation were highlighted.

#### **Visible light activation**

Adhesives have been developed and now contain a diketone and an amine. Camphorquinone is a commonly used diketone which rapidly forms free radicals in the presence of an amine and radiation of the wavelength 460-485 nanometers and intensity (Combe, 1985).

Light activated materials are generally supplied as a single paste which is unstable in the presence of either ultraviolet or high intensity visible light.

Tavas and Watts (1984) demonstrated the bonding of orthodontic bracket by transillumination of a light cured composite resin in an in vitro study. They found that light cured composite resin was potentially as effective as the chemically cured composite resins.

King et al. (1987) compared the tensile and shear bond strengths of lingual orthodontic brackets achieved with various lights (Silux, Heliosit, Heliosit Ortho) and chemically cured resins (Concise, Right-on) and found that the light

cured systems produced lower bond strengths than the chemically cured systems.

Greenlaw et al. (1989) compared the bond strengths of a chemically (Unite-heavily filled resin) cured system with a visible light (Heliosit-lightly filled resin) cured system 1 hour and 30 hours after curing. They found that the average shear bond strength for Heliosit was less than 50 percent of bond strength for the Unite and the average 1-hour shear bond strength of Heliosit was one fourth of the 30-hour bond strength. They explained that the reduced shear bond strength of light cured system was due to the chemical processes which were initiated on exposure to light. They noted that the visible light cured composite resins contained diketones. On exposure to light, these diketones assumed an excited triplet state that allowed them to combine with amines to form free radicals. These free radicals were responsible for initiating the polymerization process. Furthermore, on completion of light activation, most of the free radicals were produced at the periphery of the bracket where total light exposure was available. Time was then required for diffusion of these free radicals to take place to polymerize the resin under the bracket base and so increased the bond strength. They proposed that the first arch wire should not be placed for at least 24 hours after light curing.

Joseph and Rossouw (1990) tested bond strengths 1 week after activation of the chemically (Concise-macrofilled) cured composite resin and light (Heliosit Orthon-microfilled) cured composite resin with both stainless steel and ceramic brackets. They found that the light cured and chemically cured systems with stainless steel brackets produced similar bond strengths. Even though these resins were different. It can be assumed that some extra influence was exerted on the resins before they reached their cohesive fracture strength to create a debonding of the bracket. This influence was likely to be the deformation of the metal of the bracket when the shearing force were applied. This deformation could create a fracture plane, which would propagate through the

union. Thus the properties of the bonding composite resins were masked by this deformation in the brackets when the brackets were placed under stress.

Wang and Meng (1992) studied bond strength between light (Transbond) and chemically (Concise) cured composite resins. The results revealed that the bond strength of light cured with 60 and 40 seconds of light exposure was greater than both the bond strength of light cured with 20 seconds of light exposure and the strength of the chemically cured resin of Concise. Transbond with 40 seconds was suggested for clinical application.

Chamda and Stein (1996) studied the immediate shear bond strength produced by a light cured (Transbond) bonding system in an in vitro study and compared the shear bond strength over a 24-hour period of chemically cured (Concise) orthodontic bonding system. They found that the shear bond strengths for the chemically cured bonding system were initially low, but these increased with time. The light cured sample displayed initial bond strengths of sufficient magnitude to withstand the immediate application of orthodontic forces, and the bond strengths also increased with time. The results were in disagreement with Greenlaw et al. (1989). This may be due to the different light cured resin. There was no significant difference between the bond strengths achieved by the chemically cured and light cured systems at the 10-minute, 60-minute, and 24-hour intervals. It was anticipated that the bond strength of the light cured resin would reach a peak soon after curing, and it would remain at the same level without any appreciable increase with time.

Dual cured composite resins have been developed to overcome problem with inadequate depth of cure below inlays and onlays. They combine self curing and light curing. The self curing rate is slow and is designed to cure only those portions that are not adequately light cured (Sturdevant, 1995).

Alexander (1993) determined shear bond strength and enamel damage on debonding of chemically (Concise), light (Transbond) and new dual (Crypsis) cured composite resins. He found that Concise showed greater bond strength than Transbond or Crypsis, but the fracture modes of the three adhesives were

different. Concise or Transbond was left on the tooth surface more than Crypsis.

Smith and Shivapuja (1993) compared various dual cements (Vivadent "thick", Vivadent "thin" and Reliance "fluoride releasing") in regard to orthodontic bonding and evaluated them in relation to currently used chemically cured (Concise, Right-on, Phase II and Unite) and light cured (Transbond, Reliance "light cured" and Silux) composite resins. The results showed that the shear bond strengths of the dual cements were adequate to withstand normal orthodontic forces. Vivadent "thick" had a significantly higher bond strength than any other composite resins used. Reliance "fluoride releasing" had a significantly lower bond strength than Concise.

Sargison et al. (1995) studied bond strength of chemically (Right-on), light (Transbond and Sequence) and dual (Porcelite) cured composite resins. Porcelite was found to provide higher bond strength than the other materials.

Willems et al. (1997) evaluated the peel/shear bond strength of 22 orthodontic bracket adhesives to human premolar teeth and concluded that Concise and AccuBond which were chemically cured composite resins were the materials of choice for bonding fixed orthodontic appliances to teeth. These materials combined high bond strength with a reliable bond and were easily and quickly debonded.

## **Method of testing**

The subcommittee on testing methods of the International Association for Dental Research in 1967 recommended a tensile test for measuring bond strength of resin to dental hard tissue. However, for the bracket-adhesive-enamel bond, shear forces are likely to be most critical in vivo (Alexander et al., 1993).

Beech and Jalaly (1981) stated that, in clinical use, the forces on a bracket could be resolved into shear and tensile forces, so that both modes should be tested.



Alexandre et al. (1981) said that it was impossible to apply either pure tensile or shear forces at the interfaces without giving rise to bending moments.

Arici and Regan (1997) said that shear tests tended to simulate the direction of the force applied to debond the brackets at the end of treatment or resistance to occlusal forces whereas a tensile test indicated possible failure due to archwire ligation.

Recently, Fox et al. (1994) wrote a critique of bond strength testing in orthodontics, based on an extensive review of the literatures and proposed a standard protocol for future bond strength testing in orthodontics. The following criteria were taken into account when the protocol for a present in vitro study was developed.

1. Surface premolar enamel should be used on teeth extracted from adolescent patients for orthodontic reasons.
2. Teeth should be used after 1 month, but before 6 months from extraction and should be stored in distilled water prior to bonding.
3. After bonding, the specimens should be immersed in water for 24 hours at 37°C.
4. Debonding should take place on an Instron® or equivalent machine at a cross-head speed of 0.1 millimeter per minute.
5. Care should be taken to ensure the point of application and direction of the debonding force is the same for all specimens.
6. At least 20 and preferably 30 specimens should be used per test.
7. Site of failure should be reported.
8. Statistical analysis should include survival analysis to give a prediction of the clinical situation.
9. Bond strengths should be quoted in either Newtons or MegaPascals.