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Bond Strength in Adhesive Dentistry- A Narrative Review

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Abstract:
Bond strength is the amount of force required to break the connection between a bonded dental restoration and the tooth surface with the failure occurring in or near the adhesive/ adherent interface (or) Expression of degree of adherence between tooth surface and another material. Composites are materials composed of a highly cross-linked polymeric matrix reinforced by a dispersion of glass, mineral, or resin filler particles or short fibres bound to the matrix by coupling agents. Composites are used to restore and replace dental tissue lost through disease or trauma and to lute and cement crowns and veneers and other indirectly made or prefabricated dental devices. The bond between tooth and composite has always been sensitive and bond failure is a major obstacle in the use of composite. This article reviews the importance of bond strength in adhesive dentistry and the various tests available to measure the bond strength of different materials used in tooth-coloured restorations bonded to teeth.

***Key Word**: Bonding; Adhesive; Bond strength; Shear strength; Tensile Strength; Composite.*

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I. INTRODUCTION

Bond strength is the amount of force required to break the connection between a bonded dental restoration and the tooth surface with the failure occurring in or near the adhesive/ adherent interface (or) Expression of degree of adherence between tooth surface and another material. Bond strength, is the force of debonding divided by the nominal area of the bonded interface. Units of bond strength used are megapascals (MPa), kilograms per square centimetre (kg/cm2), and pounds per square inch (lb/in2).

Composites are materials composed of a highly cross-linked polymeric matrix reinforced by a dispersion of glass, mineral, or resin filler particles or short fibres bound to the matrix by coupling agents. Composites are used to restore and replace dental tissue lost through disease or trauma and to lute and cement crowns and veneers and other indirectly made or prefabricated dental devices. The procedure of applying a tooth-coloured resin based composite material and curing it with visible, blue light which "bonds" the material to the tooth is called bonding. The bond between tooth and composite has always been sensitive and bond failure is a major obstacle in the use of composite.

II. SIGNIFICANCE OF BOND STRENGTH

When a composite restoration is placed polymerisation shrinkage of composite resin occurs which create contraction forces that may disrupt the bond to the cavity walls. Polymerization shrinkage arises as the monomer is converted to polymer and the free space it occupies reduces (approximately 20% less than that among unreacted monomers). This creates contraction stress (13-17 MPa), which has the potential to initiate the failure of the composite – tooth interface. If the forces of polymerization contraction exceed dentin bond strength, then it leads to consequences like postoperative sensitivity, microleakage, secondary caries, and microcracking of the restorative material. With adhesive use, average dentin shear bond strengths were 30 and 26 MPa with and without acid etching[1].

An increase in number of bonded surface results in higher C-Factor and greater contraction stress on adhesive bond and decreases bond strength. Configuration factor (C factor) was introduced by Feilzer et al in 1987.C factor represents the ratio between the bonded surface area of a composite restoration to the nonbonded or free surface area. Minimum bond strength of 17-20 MPa is necessary for resisting contraction forces of resin composite materials, for enamel and dentin and prevent marginal debonding. Even when modern dentin bonding agents exhibit bond strengths to dentin higher than 20 MPa, exceeding the contraction stress generated by polymerisation stress (13-17 MPa), the total contraction forces may be higher than the adhesive strength, leading to open margins[2,3,4.]

Adhesion tests, have enabled the development of improved bonding systems and techniques. Bond strength tests are done because bond strength can predict the longevity of a restoration to some extent. Bond strength tests in laboratory are used to choose between different variants of an adhesive system and to prove its clinical efficacy[5].

III. FORCES ACTING ON TOOTH

Force is an important factor of consideration especially in dental restorations in which areas over which the force applied are extremely small, the smaller the area, the larger the stress. Various types of forces are exerted on teeth during movement of mandible during mastication. The cuspal planes are taken as inclined planes. The forces acting are not only vertical, but other forces may also be exerting on these surfaces. Tooth in turn, counteracts these forces with the help of periodontal ligament and alveolar bone.
Stresses may be divided into Tensile, Compresive or Shear based on the type of force.
***Tensile stress*:** A stress caused by a load that tends to stretch or elongate a body is called tensile stress.

***Compressive stress*:** When the forceexerted by a load tends to compress or shorten a body, the internal resistance to it is compressive stress.
***Shear stress*:** The type of stress that tends to resist the sliding or twisting of one portion of a body over another is called shear stress.
Jaw movements result in concentration of stresses at thepalatal concavity and incisal edges but not as much in the midfacial, cervical, or cingulum area because the solid dentin support in those regions resist stresses better. Strength is dependent on several factors, including the stressing rate, shape of the test specimen, size of the specimen, surface finish (which controls the relative size and number of surface flaws), number of stressing cycles, and environment in which the material is tested[5,6,7].
Different types of tests are available to measure bond strength- by laboratory methods or by evaluation of bond durability and clinical performance.

IV. CLASSIFICATION OF BOND STRENGTH TESTS

Laboratory bond strength testing methods are divided into
1)***Static tests*:** In static tests, load is applied while the specimen is held fixed. Based on the bond area, static tests are classified as macro and micro tests.
i.***Macro-bond strength test***, with a bond area larger than 3 mm. It can be measured using 'shear', 'tensile', or 'push-out'(PO) protocol
ii**.*Micro-bond strength test***, with a bond area much smaller, about 1 mm or less
2)***Dynamic tests*:** the specimen is in a dynamic state. Under clinical circumstances, the adhesive interface of a restoration is exposed to cyclic, sub-critical loadings produced during chewing. It is important to supportdynamic fatigue data with static bond-strength data for better simulation of clinical scenario. Different fatigue protocols were used like Macro/Micro shear fatigue test, Macro/Micro push-out fatigue test, Micro-tensile fatigue test, Micro-rotary fatigue test and Micro-4-point-bend fatigue test.

***Static tests*:**
***Macro-shear bond strength test*:**

It was first described by Bowen in 1965.It is a commonly used test to screen adhesive strength as it is the easiest and fastest method and requires no further specimen processing after the bonding procedure.In macroshear strength tests, a composite cylinder with a diameter of about 3 or 4 mm is polymerized onto a flat, ground enamel or dentin surface after application of the adhesive system. After this, testing is usually carried out immediately, after 24 hrs, or stored in water and tested after several months. Special jigs have been used for the test.

Several different configurations are used to exert shear force which include wire loops, notched chisels, and knife edges. The composite cylinder is cut off by use of a parallel force to the surfaceof the tooth. The force taken to de-bond and separate the substrate and the composite cylinderis measuredin Newtons.

Shear bond strength measurements are very sensitive to the method of application of the adhesive and design of the testing arrangement. Since these surface tensile stresses were considerably higher than the interfacial vertical tensile stresses by approximately a factor of three, it is highly probable that fracture was initiated from the surface of the base, as confirmed by the many cohesive fractures observed[8,9].

***Macro-tensile bond strength test*:**

From 1991 to 2001, the macrotensile bond strength test was used almost as frequently as the macroshear bond strength test. In a tensile bond strength test, the test specimenis subjected to the load from either side. Bending stresses will occur if thebonded surface of the specimen is not aligned perpendicular to the loading axis. The specimen could be held by - anactive gripping in whichthe specimenis mechanically fastened to the device with the use of glue or clamps, or by a passive gripping method, in which the specimen is placed in the device without any fasteners. In this test, stresses are more uniform than in the shear test. Hence, test results are closer to the usual strength. It can be used to measure, the bond strength of cements to hard materials such as ceramics and metal alloys. The larger surface areas used in this method are more representative of what occurs clinically. Non-uniform stresses would seem more relevant during a test because occlusal forces in vivo are not uniform[5,10].

Macro-pushout bond strength test:

The push-out(PO) test, was first used in 1966 for evaluating bonding to root canal dentin. Retention of root canal posts and adhesion of root canal sealers were tested by this method. The PO test is based on generating shear stress at the interface between dentin and cement, as well as between the post and cement. An advantage of the push-out test is that the marginal adaptation (via SEM analysis) and bond strength can be evaluated with the same test specimen. The test's drawback is that minor degrees of composite swelling upon water storage can induce a significant amount of friction, independent of adhesive performance[5,10].

Micro-Bond Strength Tests:

Micro-bond strength tests fall into three types: **Micro-tensile,Micro-shear, or micro-push out tests**depending on the stresses subjected on the test specimens.

Micro-shear bond strength test:

The Micro-Shear Bond Strength (µSBS) test was introduced in 2002 and allows testing of small tooth areas. Wire loop methods have been commonly employed to de-bond the specimen in µSBS tests to evenly distribute stresses associated with shear loads in adhesive systems. Compared to the macro-shear bond strength test, the µ-SBS test is more advantageous: it has fewer internal defects:it has homogeneous stress distributions at the interface due to the use of smaller specimen;it does not require an additional specimen trimming process after the bonding procedure, which avoids pre-testing failures. Micro-shear tests are used for those substrates (such as glass ionomers or enamel)with properties that make them particularly susceptible to the specimen preparation[11].

***Micro-tensile (µTBS) bond strength test*:**

This test method was first developed by Sano et al., in 1994 by bonding adhesive resins to the flat occlusal surface of teeth and then coveringith with composite resin. The specimen is sectionedvertically using slow-speed diamond sawinto several serial sections after curing and storing in water. The slabs which consist of resin composite in upper half and dentin in lower half are then trimmed into1mm-by-1mm sticksusing an ultrafine diamond bur. To improve stress distribution, some approaches trim such sticks to dumbbell or hourglass shapes. Interfacial stress during sample preparation resulted in a number of pre-test failures.So, some laboratories have recommended using only the unnotched sticks or a "non-trimming" preparation technique. Following sample preparation, test specimens are mounted on a variety of jig designs using fast-setting adhesives.Regardless of design, jigs must ensure that test specimens are subjected to tensile strain only. Bending forces during load application can arise from non-parallel alignment of the specimen with direction of force and/or uneven gripping forces.

***Advantages*:**

a. More adhesive fractures, fewer cohesive fractures (cohesive fractures are supposedly not desirable because they do not test the true interfacial bond strength);
b. higher interfacial bond strengths can be measured;
c. ability to measure regional bond strengths;
d. means and variances can be calculated for single teeth;
e. permits testing of bonds to irregular surfaces;
f. permits testing of very small surface areas; and
g. facilitates examination of the failed bonds by SEM.

***Disadvantages*:**

a. Labor intensive;

b. Technical demand;
c. Dehydration potential of these smaller samples;
d. Difficulty in measuring bond strengths lower than 5Mpa;
e. Difficulty in fabricating specimens with consistent geometry;
f. Easily damaged specimens and loss or fracture of post-fracture specimens.

***Micro-push out test*:**

Micro-push out test is used for measuring bond strength of luted fiber posts. It is a modification of the Push Out test. This test involves the sectioning of the coronal portion of the tooth perpendicular to the long axis with a lowspeed saw to obtain a radicular dentin disc specimen with thickness less than or equal to 1 mm.The load is applied to the apical side of the root dentin disc to avoid any limitation of post movement due to post space taper. The peak force at which the post /luting extrudes from the radicular dentin disc is noted. This force value (expressed in Newton) divided by the area ($A = 2\Pi rh$ where pi is the constant 3.14, r is the post radius, and h is the thickness of the dentin disc in mm) of the bonded interface gives the bond strength. This test is more dependable to estimate bond strength of bonded post than micro-tensile testing[12,13].

***Dynamic tests*:**

The known approaches for determining fatigue which are the Stair case approach or the fatigue life approach whencompared was not found to be a good indicator for the fatigue behavior of the bonds. But there is no standard established for fatigue testing of adhesives.

Microtensile fatigue testing:

Fatigue testing which is done at a frequency of 2 Hz, simulating a clinically normal chewing activity, might have the best comparison with clinical outcomes and henceit could be considered and recommended for invitro laboratory testing for matching clinical situation.

***Fractographic Analysis*:**

Fractographic analysis involves interfacial phases,pattern and direction of the crack propagation with the crack initiation, details of the fracture (single event or fatigue; brittle or ductile), and the stages along theplane of fracture. The failure is classified as adhesive failure, cohesive failure and mixed failure. The adhesive failure is a failure occurring at the dentin/adhesive interface or the adhesive/resin interface. The cohesive failure is a failure occurring inside the resin or dentin. Mixed failure includes both adhesive failure and cohesive failure[5,11,12].

IV. Conclusion

Resin-based composites shrink as they polymerize and contraction stresses of up to 7 MPa develop within the resin. But when resin is bonded to a single surface, as they are for bond strength studies, flow relaxation occurs relieving some of the contraction forces and therefore, these values are not realistic. Greater standardization of test methods and combining dynamic fatigue test results could improve the clinical significance of studies on dentin-resin bond strength. Dentin bond strength data may be of some use in the laboratory during the development of new adhesives but cannot and should not be used as a means of predicting clinical performance, whether directly or by inference. Additional laboratory tests such as microleakage tests, gap evaluation tests, and bond durability tests should be conducted to predict clinical performance.

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