IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)
e-ISSN: 2279-0853, p-ISSN: 2279-0861.Volume 20, Issue 6 Ser.12 (June. 2021), PP 28-32
www.iosrjournals.org

Method for assessing the bond strength of dental restorative materials; An overview

Dr. Paromita Mazumdar[a] , Dr. Soumya Singh[b] , Dr. Debojyoti Das[c]
a- Professor and Head, Department of Conservative Dentistry and Endodontics, Guru Nanak Institute of Dental Sciences and Hospital
b- Post Graduate Trainee, Department of Conservative Dentistry and Endodontics, Guru Nanak
c- Reader, Department of Conservative Dentistry and Endodontics, Guru Nanak Institute of Dental Sciences and Hospital

Abstract
Bond strengths achieved while testing in laboratories are the key for selection of adhesive systems. Longevity of a restorations can be predicted to some extent based on bond strength of adhesives. There have been several discrepancies within the reported bond strengths of various materials. Bond strength of the adhesive system is affected by a large number of factors, which makes the comparison among studies difficult. Throughout the years, laboratory evaluations have been the basis for clinicians to choose the adhesive systems in their daily practice. However the validity of bond strength tests to predict clinical performance of dental adhesives is yet to be justified. The realization of an adequate and valid method for assessing bond strength is a difficult endeavor. Different types of test have been utilized to assess the strength of a bond, which has its own advantages and disadvantages. Bonding strength is the strength required to rupture a bond formed by an adhesive system and the adherent. Often, the test involves the measurement of the shear and flexural bond strength of the adhesive system. This review focuses on aspects associated to various bond strength test methods used to test the adhesion between tooth and the restorative materials and their mechanics.

Keywords: *Bond strength test; push-out; shear; tensile; variables.*
Running title: Method for assessing the bond strength of dental restorative materials

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Date of Submission: 15-06-2021 Date of Acceptance: 30-06-2021

I. Introduction

Bond strengths achieved while testing in laboratories are the key for selection of adhesive systems. Longevity of a restorations can be predicted to some extent based on bond strength of adhesives. There have been several discrepancies within the reported bond strengths of various materials. Bond strength of the adhesive system is affected by a large number of factors, which makes the comparison among studies difficult.1 Throughout the years, laboratory evaluations have been the basis for clinicians to choose the adhesive systems in their daily practice. However the validity of bond strength tests to predict clinical performance of dental adhesives is yet to be justified.2,3 The realization of an adequate and valid method for assessing bond strength is a difficult endeavor.4 Different ways can be used to measure the bond strength. It is important to understand how the bond strength values are determined. Different types of test have been used to assess the strength of a bond, each with their own strengths and flaws.1 Different companies manufacture products which can be compared at the same level. For such comparisons it's good to know which method of bond strength testing was used.4 Bond strength is the strength required to rupture a bond formed by an adhesive system and the adherent. Hence the purpose of this review is to analyze the reliability of various methods of testing bond strength of adhesive between the tooth and restorative materials.5

Adhesion is the attraction process between dissimilar molecular species, which have been brought into direct contact. Whereas the attraction between two similar molecules is known as cohesion . In situations involving an adhesive and a substrate, the overall bonding effectiveness can be determined by combination of adhesion and cohesion.5

Bond
"A link between atoms in molecules or compounds is known as bond or chemical bond in chemistry."4

Types of bond6
- Chemical bond- (Eg: In resin based materials chemical bonding occurs due to crosslinking of the polymer(s) within the material)

- Mechanical bond- (Eg: zinc phosphate, which does not bond chemically to the tooth surfaces and its bonding is possible only through mechanical interlocking between the restoration and the tooth)
- Combination of both

"A **chemical bond** is the link between atoms, ions, or molecules that forms chemical compounds." In ionic bonds the bond results from the electrostatic force of attraction between oppositely charged ions while in covalent bond it occurs through the sharing of electrons. Chemical bonds such as ionic, metallic and covalent bonds are classified as "strong bonds" or "primary bonds" whereas dipole-dipole interactions and hydrogen bonding are classified as "weak bonds" or "secondary bonds".6

"Mechanical bonding is a kind of bonding where the adhesive locks in the voids or pores of the surfaces or holds the surfaces together." In this type of bonding, physical locking occurs between the adhesive materials and the surface.6

Uses of bonding in dentistry7

1. Bonding of directly placed resin-based restorative materials.
2. Bonding of indirectly placed restorative materials.
3. Bonding of ceramic restorations.
4. Bonding of amalgam restorations.
5. Repair existing restorations.
6. Treatment of cervical abrasion.
7. Bonding of prefabricated and cast posts.
8. Sealing of pits and fissures of posterior teeth.
9. Reattachment of fractured tooth fragments.
10. Reinforce fragile roots internally.
11. Bonding orthodontic brackets.
12. Bonding of periodontal splints.

Bond strength testing

Bond strength is the adhesion between bonded surfaces. It is measured by the strength needed to separate the bonded layers from each other. Bond strength is conventionally measured in terms of the amount of energy required to break the bond, in **kJ**/mol or kcal/mol.3

A bond test is used to find out the ability of the chemical bond within the adhesive system to be in contact with a surface or material under stress. In other words, it is the ability of an adhesive to hold two materials together under stress. After the adhesive has been applied and allowed to harden, the bond strength of the adhesive system is tested by either applying a force in an attempt to remove it from the material directly to the adhesive or to the material that has been connected by the adhesive. The force is then applied to the bond until it fails.5

Purpose of Bond Testing:

Bond tests are used to determine the bond strength of an adhesive. The bond strength of a material may be reflected as its overall "stickiness" and depends on various factors such as the type of stress the bond experiences, the temperature at which the test is done and the direction of the force applied to the bond as in case of shear bond testing which may require more force to be broken than in direct tension.6

Types of Bond Tests:8

There are different types of method for bond testing. The commonly performed bond tests in dentistry are tensile, shear, torsional, Impact, and pull-off tests. Under a given direction or type of stress the bond test is used to determine the adhesives' bond strength. Bond testing can be done in two forms, either the ability of the adhesive which when applied as a type of coating on the surface material to remain in contact with the material under stress or as its ability to hold the two substrates together while under stress when applied between two rigid substrates.

Types of testing

-There are two types of testing: Static tests and dynamic tests

Static tests

Static tests are more commonly used tests. It utilizes the application of forces to test a stationary sample.
These are of two types: -

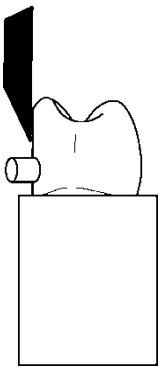
-Macro tests which are used to measure the bonded area more than 3 mm.
-Micro tests which are used to measure the bonded area smaller than 3 mm)

Macro testing

Macro tests are divided into three different methods: shear, tensile and push-out.

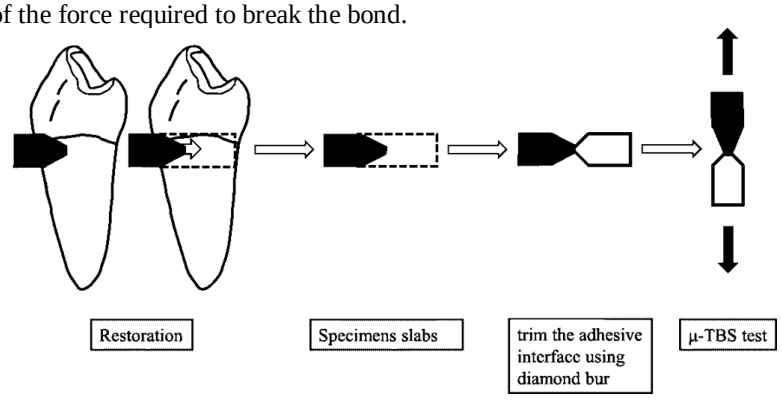
Macro-shear bond strength test (SBS)

For evaluation of new adhesives these tests are most frequently used technique.
SBS tests "the maximum stress that a material can withstand before failure in a shear mode of loading." In shear bond tests, shear loaded is done on the adhesive until it fractures.
SBS testing is the simple and easy approach of testing as the specimens require no additional manipulation or preparation after bonding of the substrate and the adhesive.
The disadvantage of SBS is that it applies a lot of force on the tooth substrate (bonded material), which can fracture before the adhesive fails. This can question the validity of results into between the failure of adhesive system and the fracture of the tooth substrate.



Macro-tensile bond strength test (TBS)

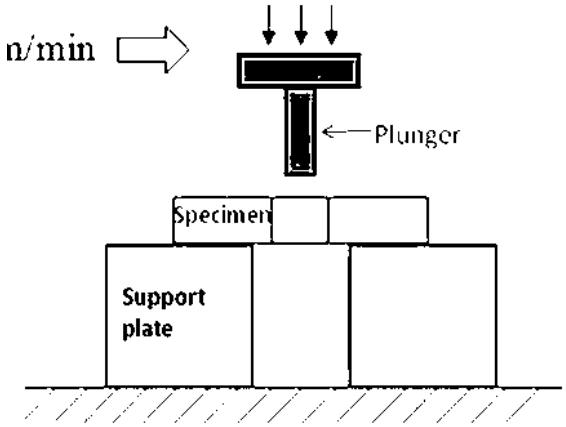
Tensile bond strength test is less commonly used than shear bond strength. This method is used for evaluation of the bond strength of cement to metal alloys and ceramics in dentistry.
In tensile bond strength tests, after the loading of specimen into a mechanical testing machine and held in place, a force is perpendicularly applied to both the sides of the sample which prevents its bending.
The advantage of TBS testing over SBS test is the uniform distribution of stress in the test. This provides a more exact information of the force required to break the bond.



Push-out test (PO)

To test the strength of the bond between adhesives and dentin such as testing of bonds of posts luted in root canals and root-canal sealers, push-out testing is done.
With this method, a tapered cylindrical hole is punched into a 1-2mm thick dentin slice by researchers. The inside of the hole is filled with composite material after coating with adhesives.
These tests provide information about the bond failure due to the removal of the composite. The bond fails parallel to the cement and dentin interface, which mimics clinical conditions better than shear bond strength tests. Sample preparation and method of testing push out bond strength are extremely time-consuming, and results replications are complicated.

Micro testing:
Micro tests are used to test small areas in specimens. Micro tensile, micro push-out and micro shear testing are the three methods of micro tests,



Push-out test (PO)

Micro-Shear Bond Strength Test (µSBS)
In 2002 micro shear bond strength test was introduced. Specimens required for µSBS testing are small and multiple specimens can be prepared from one tooth. The test provides a uniform technique and eliminates parameters that affects the results of bond testing. It is typically used to specimens that are too delicate for the stressors of micro-tensile bond testing such as glass ionomers, enamel, or other properties of the restorative materials. When compared to traditional SBS, micro shear bond tests are considered to be less relevant.
Micro-tensile bond strength test (µTBS)
Although it requires extensive specimen preparation and are technique-sensitive, micro tensile bond strength tests are efficient and have advantages than shear bond strength tests.

In this technique, more distribution of force is provided at the interface and failure occurs entirely at the bond rather than it occurs in other surfaces of specimens in shear bond strength tests. µTBS are more accurate but for measuring bond strengths less than 5 MPa these tests are not reliable.

Micro push-out test (µPO)
Micro push out tests is the variation of the macro push out test. It has to be investigated completely as other approaches. Bond strength measurement of luted fiber posts are done using this method. The specimen prepared for the test are dentin disks of 1 mm or less in thickness. Its accuracy is still undetermined as it usually results in values higher than that of normal push-out methods.

Dynamic tests
These are the accurate reflection of clinical situation since a bond rarely undergoes stationary loading. Long-term effectiveness of adhesives is better provided by these fatigue tests. Having the advantage of more clinical replication, dynamic tests are not frequently used because these tests take more time and technique sensitive when compared to static methods of bond strength tests. No standard method of testing adhesives' bond strength has been made available by today. That is why dynamic methods of bond strength testing are difficult to replicate or quantify.
There are numerous varieties of dynamic tests which are present. This includes micro and macro shear, micro tensile, micro rotary, macro tensile and 3 and 4 micro point bend methods.

Factors that can affect testing
Bond-strength testing can be affected by various other factors in addition to the methodologies used for assessment.
The composition of tooth plays important role. Bovine dentition has dentinal tubules which are larger in diameter and dentin are close to the pulp. This can affect the validity of the test regarding human teeth. In

human beings, the test results can be affected by the type of tooth tested such as third molar or teeth which have carious lesions can result in variation of bond-strength values. 9,10
As the surface area increases the bond strength decreases. Hence, the results can get affected by the size of specimen.
Higher bond strengths have been displayed by adhesives higher dentin which are in the superficial layers, while as the dentin deepens, the bond strength lowers down.
Additionally, pressure in pulp, properties of restorative materials, Mechanical testing machine configurations and errors by operator can all affect the results in testing.
However immediate bond strength can be simply measured, determining the long-term bond strength is difficult because of the potential diminishing effectiveness. Although aging factors such as mechanical loading, thermocycling, enzyme degradation and water storage are used in lab testing, these situations might not simulate the clinical situations to which adhesives are exposed. Hence, clinical behavior cannot be aligned with the lab results.11

Assessment of tests

The bond strength of adhesive is an essential factor in success of restoration, investigators advise that the analysis of bond strength should be combined with other factors such as bond durability, gap evaluation and microleakage tests and should be taken into consideration.

The consideration for clinicians is the data which is to assess a material's long-term performance exceeding 24 hours lab testing what the manufacturers present. With the limited available data, the adhesives with claims to have a very durable and strong bond have shown lower bond strengths over time in aging experiments.12

II. Conclusion

Every effort should be made to design a test methodology which is standard for evaluating the bond strength test since many factors which are not under control affect bond strength measurement may lead to variations. Results of the current bond testing methods shouldn't be used to make direct inferences on the clinical behavior of materials however they can be used for comparison of materials under the same laboratory settings. Micro-tensile bond tests provide many advantages over the shear tests, as shear and micro-shear tests, result in non-uniform stress distribution, stress concentration at the substrate area, although these methods are technique sensitive and labor intensive. Currently, the challenge in adhesive dentistry is to know the durability and clinical performance of adhesives and making the adhesive-tooth interface more resistant to aging, thereby rendering the restorative treatment more predictable in the long run.

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Dr. Paromita Mazumdar. et. al. "Method for assessing the bond strength of dental restorative materials; An overview."*IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)*, 20(06), 2021, pp. 28-32.