

Time to abandon traditional bond strength testing?

In A. J. Kinlock's classic book "Adhesion and Adhesives – Science and Technology" published in 1987 by Chapman and Hall, adhesion is referred to as attraction between substrates. In Kinlock's book it also becomes evident that the level of adhesion forces operating across an interface cannot usually be measured by mechanical tests. Despite such a strong statement by a world leader in adhesion science, a large number of papers presented at scientific meetings and submitted to dental journals deal with different bond strength values. These papers tend to give the reader the impression that the property "bond strength" is an inherent material property. However, a closer look at the majority of these papers reveals that the measured strengths have standard deviation values often 25% and more of their mean strength values. If the strength values were true inherent values, such a large variability would not exist. Thus, the notion that bond strength values are inherent material properties is simply incorrect.

It is well known in materials science that measured bulk strength values are several magnitudes lower than the theoretical material strength, a difference that is caused by defects introduced during the processing of materials. It is also known that these defects have different sizes and are distributed within the material and on its surface. It is the stresses that concentrate around flaws that usually trigger fractures. A specimen with a cross-sectional area of 1 mm² can have a flaw size near 1 mm² and remain a cohesive specimen. By the same token, a specimen with a cross-sectional area of 25 mm² could have a flaw size 25 times that of the 1 mm² specimen and still remain cohesive. From fracture mechanics we know that larger flaws increase stress concentration more than smaller flaws; thus the conclusion can be drawn that the measured strength of smaller specimens will be higher than that measured for larger specimens. This is also quite well demonstrated in the dental literature when we compare bond strength values generated on specimens of different sizes. For example, so-called microtensile bond strengths are higher than tensile bond strengths measured on larger specimens. In fact, Leonardo Da Vinci was one of the first to notice that larger specimens

were weaker than smaller ones. He discovered that the strength of a longer wire was lower than the strength of a similarly thick, but shorter wire. His findings can be explained by assuming that the probability of finding a larger flaw increases as the volume of a specimen increases.

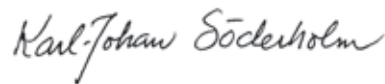
The fact that dentin bond strength values are associated with large standard deviations and that strength values are directly related to defects suggests that a key reason for failures is defects introduced during the bonding procedure. Thus, different operators introduce different forms and numbers of defects, resulting in the variability in test results among operators. Such differences are well documented in the literature. From a clinical point of view, it seems reasonable to assume that more defects are introduced during restorative procedures than during the making of test specimens for strength testing. By assuming the presence of defects in clinical restorations, one can foresee that many of these flaws will grow as a result of occlusion, causing fatigue of the restoration. Such a behavior can very well explain why some bonded restorations fail after some time in service without being pulled apart like in a bond test.

By using the above argumentation, it seems the time has come for us in the dental community to turn our attention toward a better understanding of the fracture mechanics of bond failures of restorations rather than focus on traditional strength measurements. To better understand the failure mechanism of bonded restorations, we need to characterize the surfaces where debonding has occurred clinically, not just grossly identify them as adhesive, cohesive and mixed failures, but rather by use of fractography. Based on our own experience, debonded restorations usually leave a thin resin film on the dentin surface, indicating a failure occurred somewhere within the adhesive. Sometimes part of a restoration fractures and debonds, while remaining restoration parts stay bonded to the tooth. In this case, a likely cause of failure is a crack that propagates along the interface until it reaches a defect in the adhesive-composite transition, causing the crack to deviate into the composite and cause a composite fracture. The only time dentin fractures linked to bond failures are observed clinically are when cusps fracture.

Considering these clinical failure modes, we may ask how we can correlate the results of in vitro bond studies with clinical observations. In in vitro studies, it is more common to find so-called cohesive and mixed failures than in true clinical situations where adhesive failure is the normal failure mode. In addition, under clinical conditions, true cohesive failures would not even be called bond failures, while in most in vitro studies they are included in bond strength results.

We are all aware that the objective with in vitro evaluations is to predict the clinical success of dentin adhesion. Today we also know that in vitro bond tests are questionable when it comes to achieving such a goal. Instead, it is high time to explore other testing approaches that rely on methods other than traditional bond strength testing. For example, one advantage of a true fracture analysis

is that it better identifies the site where the failure is initiated and how the crack propagates. Such studies can be performed by collecting more clinical data in the form of replicas. By studying these replicas, we would be able to better understand and develop a theory about the mechanism of dentin bonding as well as different failure mechanisms. It is really only when we have that information that we are ready to take the next major leap in the field of adhesive dentistry.



Karl-Johan M. Söderholm