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Adhesion to tooth structure: A critical review of “macro” test methods

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ABSTRACT

Objectives. Bond strength between adhesive systems and the tooth structure is influenced by a large number of variables, which makes the comparison among studies virtually impossible. Also, failure often times propagates into the dental substrate or the composite, deeming the results questionable at best. In spite of the increased popularity gained by micro-tensile and micro-shear tests, in vitro evaluations using specimens with relatively large bonding areas remain frequent. This review focuses on aspects related to specimen geometry and test mechanics of “macro” shear and tensile bond strength tests.

Methods. Besides information drawn from the literature, the effect of some parameters on stress distribution at the bonded interface was assessed using finite element analysis (FEA).

Results. Bond strength tends to increase with smaller bonding areas and with the use of high elastic modulus composites. Stress concentration at the bonded interface is much more severe in shear compared to tension. Among shear methods, the use of the chisel shows the highest stress concentration. Within the limits suggested by the ISO/TS 11405, crosshead speed does not seem to influence bond strength values. Pooled data from currently available adhesives tested in either shear or tension showed 44% of adhesive failures, 31% mixed and 25% cohesive in the substrate (tooth or composite). A comparative bond strength study involving three adhesive systems revealed similarities between “macro” and “micro” counterparts regarding material ranking, whereas “macro” tests presented a higher incidence of cohesive failures.

Significance. Simplicity warrants “macro” bond strength tests an enduring popularity, in spite of their evident limitations. From a mechanical standpoint, knowing the stress distribution at the bonded interface and how it is affected by the materials and loading method used is key to explain the results.

Contents

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1. Introduction

Over the years, clinicians have relied upon laboratory evaluations to choose which adhesive systems to use in their daily practice. Though the validity of bond strength tests to predict clinical performance of dental adhesives is questionable [1,2], recent evidence shows that clinical results can, to some extent, be estimated based upon laboratory results [3–5]. Moreover, mechanical testing of bonded interfaces has provided some valuable information in terms of identifying substrate variables [6,7] and helping define guidelines for application procedures [8].

Until the mid-nineties, shear and tensile bond strength tests were performed exclusively in specimens with relatively large bonded areas, usually 3–6 mm in diameter (approximately 7–28 mm^2). However, the validity of expressing bond strength in terms of nominal (*i.e.*, average) stress has been questioned due to the heterogeneity of the stress distribution at the bonded interface [9–11]. Moreover, cohesive failure of both the composite and the dental substrate is a common occurrence, precluding an accurate assessment of the interfacial bond strength [12]. The need for new methods to overcome these limitations led to the use of specimens with small bonding areas (*i.e.*, below 2 mm^2), in the so-called micro-tensile and micro-shear tests [13–15].

In spite of the increased popularity of the "micro" bond strength tests and the criticism endured by the conventional tensile and shear methods, the number of articles using "macro" tests published in recent years remains high, meaning that a lot of the available data on dental adhesion still comes from mechanical tests performed in specimens with large bonded areas (Fig. 1). The preference for conventional shear and tensile tests is justified because they are easy to perform, requiring minimal equipment and specimen preparation. However, though a lot of information can be found on specimen geometry and other testing variables for "micro" bond strength tests [16–18], the same is not true for the "macro" tensile and shear tests.

Reviews published in the past evidenced a concern with the bonding substrate and specimen storage conditions, only minimally discussing the variables of the mechanical test itself [1,12,19–21]. The International Organization for Standardization (ISO) technical specification ISO/TS 11405 [22], published in 1994 and last revised in 2003, reflects this tendency, describing with greater detail the characteristics and preparation of the tooth substrate for the bonding procedure, and leaving aspects such as bonding area, testing assemblies or loading conditions more vague. As a result, a wide variety of experimental protocols is found among researchers, with evident effect on the outcomes [23,24]. A systematic review with meta-analysis identified composite type, bonding area, testing mode (shear, tensile or micro-tensile) and crosshead speed as factors that significantly influence bond strength, along with several others related to the substrate, specimen storage conditions and thermocycling [25]. The type of device used for load application was also shown to affect the results [26–29].

The purpose of this article was to review aspects related to specimen geometry and test mechanics that may influence "macro" shear and tensile bond strength results. Finite element analysis (FEA) was used to assess the effect of selected variables on the stress distribution at the bonded interface.

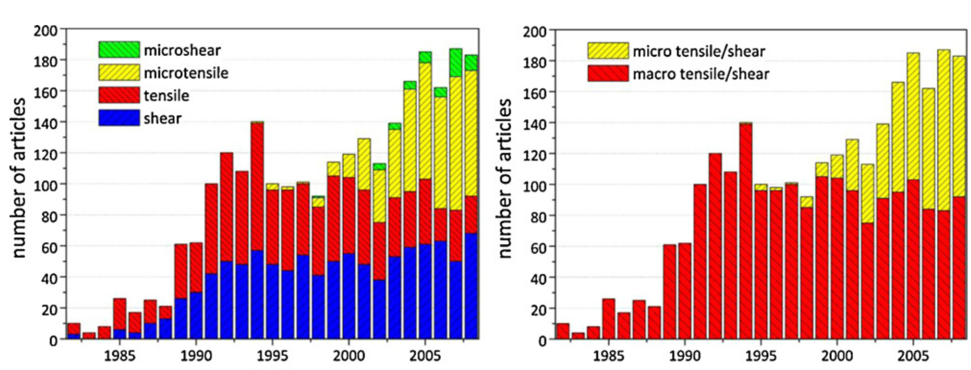

Fig. 1 – Number of articles/year published on dentin and enamel bond strength between 1982 and 2008, according to www.scopus.com. Left: articles grouped by testing method, right: articles grouped by specimen dimensions, *i.e.*, "macro" or "micro" (publications on bond strength of orthodontic brackets to enamel were not included).