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On edge chipping testing and some personal perspectives on the state of the art of mechanical testing

*G.D. Quinn**

Materials Measurement Science Division, Stop 852-9, National Institute of Standards and Technology, Gaithersburg, MD 20899, USA

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ABSTRACT

Objective. The edge chipping test is used to measure the fracture resistance of dental restoration ceramics and resin composites. This paper focuses on the progress of evaluating chipping resistance of these materials and also on the progress of standardization of this test method. This paper also makes observations about the state of the art of mechanical testing of ceramic and composite restorative materials in general. Interlaboratory comparative studies ("round robins") are recommended.

Methods. An edge chipping machine was used to evaluate dozens of materials including porcelains, glass ceramics, aluminas, zirconias, filled resin-composites, new hybrid ceramic-resin composites, laminated composite ceramics, and even polymethyl methacrylate based denture materials. Force versus distance data was collected over a broad range with different indenters. Several chipping resistance parameters were quantified.

Results. Older restorative materials such as feldspathic porcelains and veneering materials had limited chipping resistance, but more modern ceramics and filled composites show significant improvements. A yttria-partially stabilized zirconia had the greatest resistance to chipping. Much of the early work on edge chipping resistance of brittle materials emphasized linear force versus distance trends obtained with relatively blunt Rockwell C indenters. More recently, trends for dental restorative materials with alternative sharper indenters have been nonlinear. A new phenomenological model with a simple quadratic function fits all data exceptionally well. It is loosely based on an energy balance between indenter work and fracture and deformation energies in the chipped material.

Significance. Although a direct comparison of our laboratory scale tests on idealized simple geometries to clinical outcomes has not yet been done, anecdotal evidence suggests the procedure does produce clinically relevant rankings and outcomes. Despite the variations in the trends and indenters, comparisons between materials can easily be made by chipping convenient block-shaped specimens with sharp conical 120°, Vickers, or Rockwell C indenters at a defined edge distance of 0.5 mm. Broad distance ranges are recommended for trend evaluation. This work has provided important information for standardization.

* Tel.: +1 301 975 5765; fax: +1 301 975 5334.
E-mail addresses: george.quinn@nist.gov, geoq@nist.gov

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1. Introduction

The edge chipping test was originally developed in the late 1980s to study hard metal cutting tools at the National Physical Laboratory in London [1–4]. Chips are formed by advancing an indenter into a material near an edge as shown in the insert of Fig. 1. The force required for chip formation, *F*, increases with distance from the edge, *d*. The shape of the chip usually is independent of the material tested [1]. J. Quinn pioneered the application of this method to dental restorative materials in the mid-1990s to the time of her untimely death in 2008 [5–12]. This work continued over the ensuing years [13–17] including three papers in this Journal in 2014. Other groups have used it for the evaluation of human teeth [18], dental restorative materials [19–24], and structural ceramics in general [25–30]. Clinical longevity studies have shown that chipping is a leading cause of restoration failure [e.g., 31–35]. In some cases it is possible to repair restorations, but in others a complete replacement is needed. Scherrer [36] showed eight clinical failures studies of which six were chipping of the veneer. Chipping in veneers has been specifically identified as a problem in modern zirconia restorations [37–39]. In other cases chipping can occur at a crown margin during manufacture [19,40,41] and can weaken the restoration dramatically. Major cracks emanate from the margin starter chips and split a crown in half [42,43] due to hoop stresses. Unfortunately, the extent of the chipping and the type of chipping is often unreported in clinical studies. Ref. [44] is an interesting exception where six chipping modes were reported for 22 class IV restorations in a clinical study of 455 composite resin anterior restorations. Chipping in natural teeth was cited as a common problem associated with tongue piercing jewelry [45].

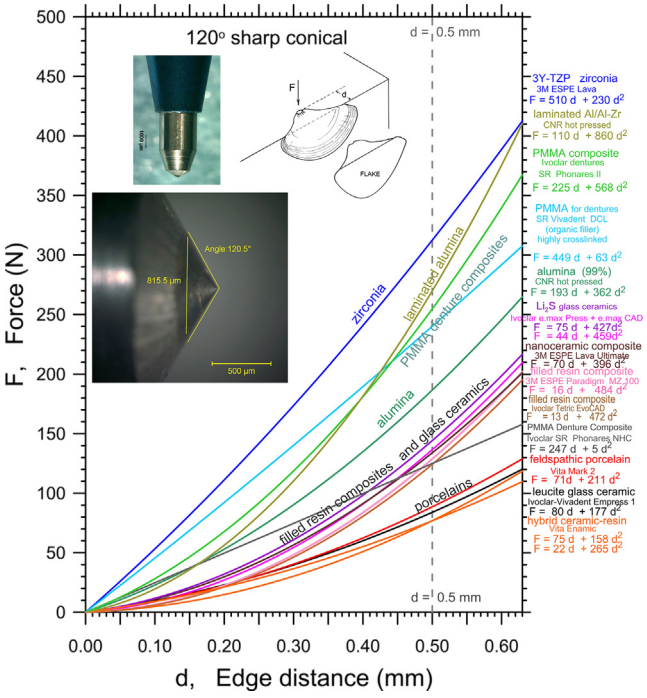

Fig. 1 – Edge chip results for fourteen materials obtained with the sharp conical 120° indenter.

Although the in vitro edge chip tests use specific indenters on test blocks with carefully prepared edges, the chips physically resemble some types of in vivo failures [36,41–44]. Our in vitro work [5–17] has focused on testing block-shaped specimens for the most part, but there is no reason that human [13,18] or artificial [14,24] teeth cannot be tested as shown in Fig. 2.

A short review paper on the edge chipping test method as applied to dental materials was prepared in 2012 [12], but there has been substantial progress in the last 2 years [14–17]. Test procedures have been refined. The influence of indenter type has been clarified and it appears that material rankings do not change very much between indenter types. The actual force–distance trends do vary with indenter. Indenter sharpness was identified as a key factor in large part due to sideways wedging forces created during the chipping process [16]. It was shown that the Vickers indenter with face angles of 136° 30′ and edge angles of 148° was equivalent to a 140° sharp conical indenter. Unlike the early assumption that most materials follow linear trends, we now know that nonlinear behavior is common especially for dental restorative materials chipped with sharp indenters. Although a full characterization is best achieved by collecting data over a broad force and distance range, a simple comparison of materials can be made by measuring the "edge strength," which is the force to make a chip at the arbitrary distance of 0.5 mm as done by Watts et al. [19–21]. Simple block shaped specimens that are at least 5 mm thick are adequate for most purposes. Comparative data taken on brittle denture materials showed that the data taken from flattened teeth matched the rectangular wear block data [14].

A new phenomenological model based on energy concepts was introduced in 2014 [16,17]. Indenter energy is converted into fracture and deformation energies in the chipped material. A simple quadratic equation that relates indenter force to edge chipping distance is an excellent match to the nonlinear outcomes measured on all materials tested.

This paper steps back from the details presented in the earlier papers and presents a broader view of the results and includes some fresh data. Nevertheless, the details (e.g., how well the specimen must be mounted, problems with "overchipping" and the post fracture determination of the distance) are important as this method is developed into a standard. There are two draft test method standards on the edge chipping resistance of brittle materials: one in the European committee for Standards [46] and one in ASTM International [47]. One goal of this study has been to recommend improvements or adaptations to the drafts so that the standards will be useful to the dental community.

2. Materials and methods

The 32 materials have been described previously.[1] They include feldspathic porcelains [5,6,10,12,17], leucite

[1] Commercial products and equipment are identified only to specify adequately the experimental procedures and does not imply endorsement by the authors, institutions or organizations supporting this work, nor does it imply that they are necessarily the best for the purpose.