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Development of strength in dental silver amalgam

B.W. Darvell *

Dental Materials Science, Dept of Bioclinical Sciences, Rm 2-20, Faculty of Dentistry, Health Sciences Centre, Kuwait University, Jabriya, Kuwait

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ABSTRACT

Objectives. To characterize the development of strength during the setting process of dental silver amalgam in the context of 'early strength' measurements for standards compliance testing in relation to patient instructions, and demonstrate the applicability of the Hertzian 'ball on disc' method.

Materials and methods. Sixteen dental silver amalgam products were tested using the 'ball on disc' protocol at 1, 2, 3, 4 and 24 h after setting at 37 °C in air. The mixed materials were packed into a tapered steel disc mold (10 mm diameter, 3 mm thick) resting on a glass surface, slightly overfilled and carved level with a sharp edge, then ejected at ~10 min and placed immediately into an incubator at 37 °C. Testing was in Hertzian mode, using a 20 mm steel ball, with the specimen resting on a disc of glass-filled polyamide ($E = 10$ GPa) at a cross-head speed of 0.2 mm/min on a universal testing machine (E3000, Instron). The load at first crack was recorded, as was the number of radial cracks produced.

Results. Radial cracking into 2–5 pieces, in a clinically-relevant (non-explosive) mode was observed in all cases. Considerable variation in setting rate between products, as indicated by the development of load at failure with time, was found. The distribution of normalized failure load values overall was lognormal (Weibull was excluded). The RMS coefficient of variation overall was 12.4%.

Significance. The ball-on-disc test provides a facile, relevant measure of the strength of dental silver amalgam, and is viable as a standards compliance test. Early strength testing at a minimum of 2 h is suggested.

1. Introduction

Dental silver amalgam continues as a mainstay of economical restorative treatment in various jurisdictions, despite intensifying discussion of the collateral environmental problems arising from mercury-containing waste [1–4]. Safety has been debated since the 1840s, and continues unabated today [5], although the recognition of the value of the material remains [6–8]. A key aspect has been whether filled-resin materials can replace amalgam [9,10], but this is considered by some experts not yet to be the case [11,12].

Accordingly, it is appropriate that the properties and behavior of such products continue to be subject to scrutiny *vis-à-vis* treatment efficacy, and thus tested for compliance with agreed standards. It follows immediately from this that the work of the International Organization for Standardization (ISO) Technical Committee for Dentistry (TC106), and of similar national bodies, in this area ought to continue to provide guidance as to the minimally-acceptable performance in the various aspects,

* *Correspondence address*: P.O. Box 24923, Safat 13110, Kuwait. Tel.: +965 24 98 66 98; fax: +965 24 98 66 98; mobile: +965 65 62 62 50.
E-mail addresses: b.w.darvell@hsc.edu.kw, b.w.darvell@hku.hk

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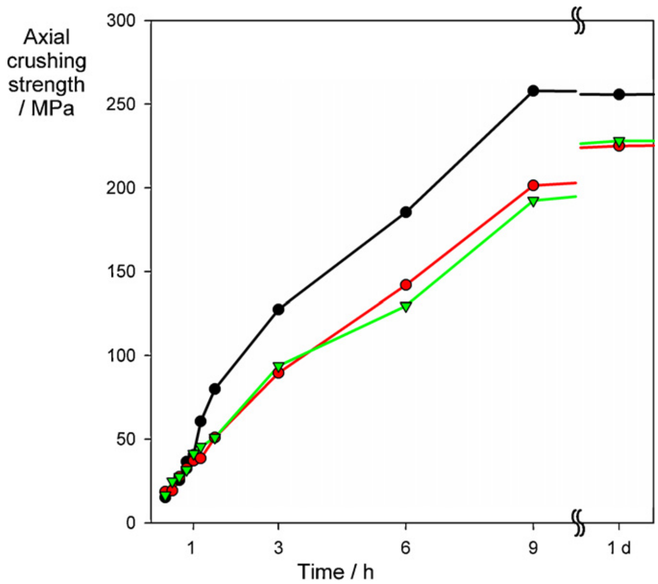

Fig. 1 – Early strength results due to Taylor et al. [17].

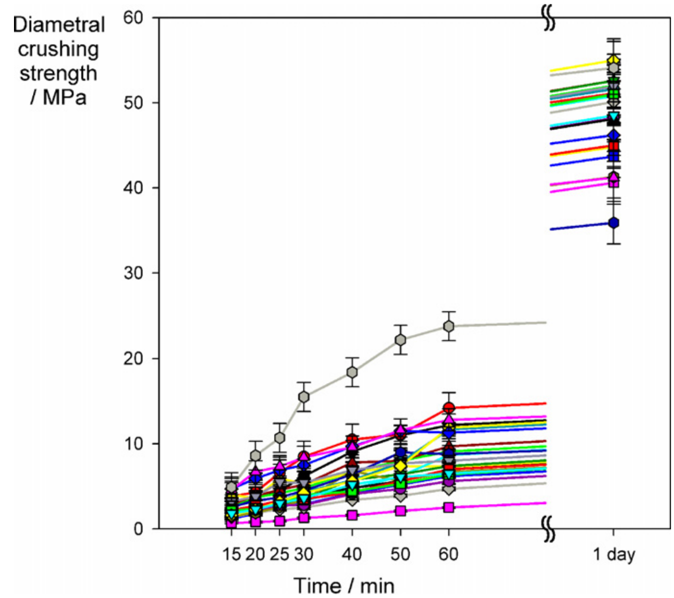

Fig. 2 – Early strength results due to Spanauf et al. [20].

and as to the tests that may be used to ascertain compliance [13]. Early strength is one such key property.

Unlike many materials used in dentistry which set through a chemical reaction, dental silver amalgam is (relatively) slow. For example, as judged by dimensional change at 37 °C, the process has not stopped at 150 h [14]. Certainly, tensile strength has been shown to increase to at least 100 h [15], and to 7 days in one instance at least [16], similar to results for ‘compressive strength’ [17]. Transverse bend strength for one alloy increased to at least 3 months [10]. However, some results are far from clear for the interval 1–7 days [18]. Very early strength has been noted to be relevant to first contact as part of the treatment process, *i.e.* for occlusal adjustment, at 15–20 min [19]. Other than that, little data has been published (Figs. 1 and 2) [17,20], a point noted elsewhere. [21] Nevertheless, it is the early strength that is of primary importance, no matter the final value, since it is the vulnerability to premature masticatory forces that is presumed to be of most concern [22]. This low early strength is generally recognized, but the implications clinically only rarely get mentioned [23]. The instructions to the patient regarding when it might be ‘safe’ to bite on a new restoration seem to be part of the oral tradition of teaching in dentistry, and vary between operator, but are always vague, with no known documentation, although “everybody says it”. This situation may arise from the absence of specific evidence, but such instructions do appear to be eminently sensible and nobody disputes their wisdom in principle. Even so, those few published studies of the development of strength have not been focused on this topic and so have made no apposite remarks. For comparison, Philips is reported to have advised that 8 h should elapse before biting, while on limited data a possible reduction to 6 h was suggested [21]. Secondly, since there is no absolute means of determining a minimum appropriate strength for amalgam (or indeed any material) there can be no absolute threshold for the strength at any chosen time after mixing or placement: how strong is strong enough? Ultimately, of course, it is unanswerable because in the engineering terms appropriate to the assessment of an object, it is the combination of strength and section in the context of the mode of loading that controls the outcome. Section depends on many factors outwith material considerations, and although it is to be hoped that the appropriate design is made to suit the material (or *vice versa*), this engineering of restorations is not part of clinical teaching as such, only rule of thumb learnt (effectively) by apprenticeship is applicable or practiced.

This absence of clarity is therefore not surprising. Nevertheless, the relevant ISO standard [24] refers to a minimum “compressive strength” of 80 MPa at 1 h (and 300 MPa at 24 h, to put this in perspective). Notwithstanding the pragmatic and political aspects of the drafting of standards [13], the choice of testing at 1 h appears to be unsupported by any documentation or other evidence (never mind the value). It would seem that the only explanation is that it is a ‘convenient whole number’: it has no intrinsic meaning, as with many such test times. This is perhaps more related to the (understandable) desire to create simple work schedules in the test house as it is to clinical reality (for example, there are not many studies that report values for anything at all between about 8 and 16 h after preparation, nor requirements to obtain such values).

The use of “compressive strength” is another matter of convenience. As has been pointed out [25], there is no such thing, and although the terms “bearing capacity” or “crushing strength” could be used it does not affect the fact that crack initiation is internal and in shear. So-called indirect tensile strength (*alias* diametral compression), often vaunted as the solution to the logical difficulty, is in fact the same class of test in all respects and offers no escape (other than scale, Figs. 1 and 2 show much the same proportion of the 24 h value at 1 h) [25]. The problem, however, is that the mode of failure in any such a test bears no relation to the clinical context, where explosive fragmentation is not known ever to have occurred. There are other problems. Parasitic stresses