DENTAL MATERIALS 32 (2016) 34–42

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.intl.elsevierhealth.com/journals/dema

Interpenetrating network ceramic-resin composite dental restorative materials

M.V. Swain[a,*], A. Coldea[b,1], A. Bilkhair[c], P.C. Guess[c]

[a] *Faculty of Dentistry, Health Science Centre, Kuwait University, Kuwait*
[b] *Vita Zahnfabrik, Bad Säckingen, Germany*
[c] *Prosthetic Department, Faculty of Dentistry, University of Freiburg, Germany*

ARTICLE INFO

Article history:
Received 17 June 2015
Received in revised form
5 September 2015
Accepted 9 September 2015

Keywords:
Interpenetrating network material
Resin infiltrated ceramic
Mechanical properties

ABSTRACT

Objectives. This paper investigates the structure and some properties of resin infiltrated ceramic network structure materials suitable for CAD/CAM dental restorative applications.
Methods. Initially the basis of interpenetrating network materials is defined along with placing them into a materials science perspective. This involves identifying potential advantages of such structures beyond that of the individual materials or simple mixing of the components.
Results. Observations from a number of recently published papers on this class of materials are summarized. These include the strength, fracture toughness, hardness and damage tolerance, namely to pointed and blunt (spherical) indentation as well as to burr adjustment. In addition a summary of recent results of crowns subjected to simulated clinical conditions using a chewing simulator are presented. These results are rationalized on the basis of existing theoretical considerations.
Significance. The currently available ceramic-resin IPN material for clinical application is softer, exhibits comparable strength and fracture toughness but with substantial R-curve behavior, has lower E modulus and is more damage tolerant than existing glass-ceramic materials. Chewing simulation observations with crowns of this material indicate that it appears to be more resistant to sliding/impact induced cracking although its overall contact induced breakage load is modest.

1. Introduction

The basis for the selection of dental materials for restorative purposes has been somewhat determined by whether the material is metallic, ceramic or polymer based. The nature of the interatomic bonding forces of each of these classes of materials dictated the mechanical response especially the elastic modulus. Requirements associated with the high contact loading and abrasive conditions on the occlusal surface, especially with posterior teeth, resulted in the development of stiffer and harder ceramic particle filled composites. However with all these classes of materials there was a distinct gap between the properties of the enamel and dentin they

---

[*] *Corresponding author.*
E-mail address: mswain@mail.usyd.edu.au (M.V. Swain).
[1] On maternity leave from.

http://dx.doi.org/10.1016/j.dental.2015.09.009

were being asked to replace. Interestingly the closest matching systems were gold and amalgam with that of enamel and some cements and highly filled composite resins with dentin. The current advent of greater emphasis on aesthetics has resulted in usage of materials with either much lower (polymer composite) or higher (crystalline ceramics such as zirconia or alumina) elastic properties than enamel. The question now arises as to how can the palette of existing dental materials for CAD/CAM based restorative dentistry be increased? The requirements for such materials not only include aesthetics, biocompatibility and longevity but also precision and rapid reliable millability to relative thin dimensions (<500 μm). Such demands, which have become more acute during the past decade, have resulted in a limited number of novel materials and approaches. Included in the former are pre- or partially-cerammed glass-ceramics as well as partially sintered crystalline zirconia and alumina ceramics. These materials generally involve a time consuming heat processing step between milling and clinical utilization.

In the past few years two alternate options have appeared on the market place. These include a very heavily particle filled resin cured at higher temperature/pressure and a ceramic based resin interpenetrating network (IPN) material, with the latter the basis of this paper. The former include Lava Ultimate from 3M and Cerasmart™ from GC. What are IPN materials? These are multi-phase structures in which the constituent phases are mutually continuous and interconnected [1]. The three-dimensional interconnectivity of IPN materials differs from traditional composites, such as discrete fiber or particle reinforced and laminated composites. As can be appreciated from previous studies the purpose of developing synthetic IPNs is driven, amongst others, by the attempt to enhance or tailor the physical properties of the constituent phases, e.g. fracture toughness [2], fracture strength [3], contact and grinding damage tolerance [4] etc. Each constituent phase within IPNs contributes its own properties resulting in enhanced effective properties of the topologically interconnected microstructure [5]. In contrast with conventional composites in which only the matrix phase is continuous IPNs exhibit some physical properties that are different from and often superior. Feng et al. [6] proposed a unit cell model to estimate the effective properties of IPNs, since for example the elastic modulus, the strength or the fracture toughness of IPNs depend not only on the volume fractions, but also, on the spatial distribution of the constituent phases. According to *Feng et al.* [6] for IPNs the reinforcing phase is able to distribute stresses more effectively in all directions. The greatest benefit (according to [5]) of network structured materials with interpenetrating phases is in distributing an enhanced resistance to various breakdown phenomena [5]. Such as, a three-dimensional reinforcement phase (e.g. polymer) offers resistance to crack propagation by bridging cracks introduced to the lower strain to failure matrix material (e.g. ceramic). In aligned fibrous composites, in contrast to IPNs, cracks propagating parallel to the fibers cannot be deflected [5]. Therefore, to develop R-curve (resistance curve) behavior, a range of inhomogeneity on more than one scale, as typically occurs in biological materials with their multiple hierarchical structures, is required, which is the case with IPNs. Even though materials with interpenetrating networks are relatively common for natural biomaterials, for instance bones in mammals and the trunks and limbs of plants, there are currently only few that are synthetically developed [5].

In dentistry a family of IPN all-ceramic systems has existed for more than 2 decades based upon the pioneering research of Sadoun and Vita Zahnfabrik dental company, namely the In-Ceram®ALUMINA group of materials. The latter materials consist of an open porous ceramic structure typically 70% dense consisting of alumina, alumina-zirconia or spinel that is infiltrated with a glass. These materials not only could be fabricated by slip casting (or milling from pre-fabricated porous blocks) to the specific shape but also there was no dimensional change upon subsequent sintering and infiltration with glass. The In-Ceram®ALUMINA system continues to have reliable clinical outcomes for applications as individual crowns in the posterior and short span bridges in the anterior region of the mouth [7].

In this paper the results of a number of recent specific studies of a commercially available material (Enamic, Vita Zahnfabrik) along with some experimental materials will be reported. In addition recent outcomes by Nguyen et al. [8] using very high pressure infiltration of sintered and unsintered ceramic blocks will be considered. Of particular importance with the latter is that sintering of the ceramic particles prior to high pressure infiltration had very limited influence upon the resultant mechanical properties. Specific emphasis will be placed upon the properties of these materials in comparison with a range of existing all-ceramic materials. Of particular importance will be to address, where possible, the issue of tolerance of these various materials to common clinical conditions namely contact and grinding induced damage.

2. Materials and methods

2.1. *IPN based dental materials*

2.1.1. *In-ceram family of all-ceramic materials*

The all-ceramic In-ceram group of ceramics, developed by Sadoun more than 25 years ago and commercialized by Vita Zahnfabrik in 1989, were the first specific dental materials to utilize the IPN concept. They also overcame the major obstacle associated with the use of all-ceramic systems namely sintering induced shrinkage of ~20% by the development of a technique that involved precision net shape forming. This consisted of utilising a combination of coarse and fine alumina particles that could be slip cast to approx. 70% density, which upon sintering to 1000–1200 °C did not shrink despite the formation of necks between the individual particles. This was achieved by the presence of the coarse grains which prevented contraction and resulted in an open fine porous structure throughout the alumina body. Subsequent infiltration of this structure with glass at 950–1000 °C, which completely wetted and under the influence of capillary forces, resulted in near completely dense structures. These materials found application as crowns in both anterior and posterior regions of the mouth and as short span anterior bridges and two unit posterior bridge structures. These materials may be considered the first successful all-ceramic system and reports on 18 year