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Influence of surface roughness on mechanical strength of resin composite versus glass ceramic materials

Ulrich Lohbauer[a,*], *Frank A. Müller*[b], *Anselm Petschelt*[a]

[a] *Dental Clinic 1, Operative Dentistry and Periodontology, University of Erlangen-Nuremberg, Glückstr. 11, D-91054 Erlangen, Germany*

[b] *Department of Materials Science, Glass and Ceramics, University of Erlangen-Nuremberg, Germany*

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ABSTRACT

Objectives. Clinical polishing leads to reduction of surface flaws sizes and thus to increased mechanical strength. The aim of the present work was to assess fracture strength of a resin composite and of a glass ceramic as a function of surface roughness and to relate the strength data to flaw sizes, microstructural and fractographic examinations.

Methods. Specimens have manufactured out of a resin composite (Tetric® EvoCeram, TEC) and out of glass ceramic material (IPS E.max® Press, EMP). Different surface roughness levels have been induced using cutting, grinding and polishing techniques and quantified under CLSM. Fracture strength was measured in four-point bending and analyzed using Weibull statistics. Indentation fracture method was used to calculate fracture toughness. Critical flaw sizes were calculated and related to microstructure. Microstructural and fractographic examinations have been performed under SEM.

Results. Fracture strength upon the glass ceramic material decreased from 441.4 to 303.3 MPa (R_a = 150 nm–1.5 μm) and upon the resin composite from 109.8 to 74.0 MPa (R_a = 300 nm–50 μm). EMP exhibited a fracture toughness of K_{Ic} = 4.14 MPa $m^{0.5}$ and TEC of K_{Ic} = 1.89 MPa $m^{0.5}$. Calculated crack lengths for EMP ranged from 28.1 μm (441.4 MPa) to 59.6 μm (303.3 MPa) and for TEC from 94.3 μm (109.8 MPa) to 207.0 μm (74.0 MPa).

Significance. Dependency of fracture strength on surface roughness is neither determined by crystallite size of the glass ceramic material nor by filler sizes of the resin composite. No significant increase in fracture strength has been observed below 0.65 μm (1000 grit) in EMP. For TEC a threshold value might be determined below 2.1 μm (320 grit).

Optimal polishing of a restoration right after placement is strongly recommended to keep an optimum strength performance through the whole clinical lifetime.

1. Introduction

An increasing amount of ceramic restorations are placed in restorative and prosthetic dentistry. High demands for aesthetic and biocompatible materials extend the significance of ceramic restorations. Clinically, the main problem having consequently been reported in literature are fractures like chipping, marginal and bulk fractures [1,2]. Major goals of modern ceramic systems are the improvement of mechanical properties and reliability [3]. In this context, the simplest

* *Corresponding author*. Tel.: +49 9131 853 4236; fax: +49 9131 853 3603.
E-mail address: lohbauer@dent.uni-erlangen.de (U. Lohbauer).

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method to increasing strength is a surface treatment by polishing. Polishing leads to reduction of surface flaw sizes and thus to improved mechanical strength [4]. Initial finishing of a restoration surface after placement induces deep flaws and requires proper polishing especially in load bearing areas and in deep fissures.

Fracture of brittle ceramics occur without measurable plastic deformation, which is due to the strong atomic bonding of ceramics. In consequence, failure can start from small flaws prior to plastic deformation. This fact is expressed by a low resistance against crack extension, that is characterized by the fracture toughness K_{Ic} [5]. Various approaches have been used to determine the effect of flaws on strength [6]. Griffith postulated for plane stress conditions an inverse square root relationship between fracture strength σ_c and critical flaw size a_c [7]:

$$\sigma_{c(t=0)} = \frac{K_{Ic}}{(\pi a_c)^{1/2}} \quad (1)$$

Brittle fracture will occur when the stress intensity K_I at a surface crack of length a_c exceeds the critical stress intensity factor, e.g. $K_I = K_{Ic}$.

Fracture resistance of resin composites is discussed controversially in literature. There is the treatment of resin composites as brittle materials, applying linear elastic fracture theory and measuring related material properties such as fracture toughness [8–10]. On the other hand dental composites exhibit plastic and visco-elastic effects, assessed by the J-Integral according to elastic plastic fracture mechanics, or a susceptibility to creep and recovery [11–13]. However, in the vicinity of a sharp surface crack tip, blunting occurs by plastic deformation, which reduces the local stress at the crack tip, thus resulting in cleavage rather than brittle rupture of the atomic bonds [14]. The brittleness (or, respectively the ductility) of a resin composite is depending on variables such as loading rate, temperature and filler loading. Fillers are reported to increase fracture toughness due to microcracking at the crack front or crack bridging mechanisms by second phase particles, e.g. filler particles [3]. Temperature increase, even far below the glass transition temperature will contribute to a rather ductile material behavior and fast fracture is reported to suppress creep and recovery phenomena [14]. Fatigue measurements in resin composites postulate a diverging fracture mechanism comparing fast fracture with cyclic fatigue [15].

In dentistry, intensive research is focused on surface polishing of resin composites. A smooth surface is desirable due to optimal biocompatibility [16]. Proper polishing of restorations minimizes possible gingival irritation, surface staining, plaque accumulation, and secondary caries [17]. In literature, no indication is provided that proper polishing substantially influences resin composite strength as observed in brittle ceramic materials.

The aim of the present work was to assess fracture strength of a resin composite and of a glass ceramic as a function of surface roughness and to relate the strength data to critical flaw sizes, intrinsic microstructure and fractographic examinations.

2. Materials and methods

2.1. Materials

The commercial lithiumdisilicate glass ceramic IPS E.max® Press (EMP) and the direct resin composite Tetric® EvoCeram (TEC) (both Ivoclar Corp., Liechtenstein) were used in this study.

The glass ceramic EMP mainly consisted of 70 wt% crystalline $Li_2Si_2O_5$ phase of 3–6 μm in length, as shown in Fig. 1. Beside that a small amount of Li_3PO_4 (lithiumorthophosphate) crystals are embedded in the glass matrix. EMP is used as a supporting structure and will clinically be covered with a veneering porcelain. This core material has been selected since the influence of surface defects on the strength performance of veneering porcelains is well understood and since slow crack growth influences are even reduced in high crystalline lithiumdisilicate structures [18].

TEC as an inhomogenous microfiller hybridcomposite consists of a dimethacrylic matrix system and 48.5 wt% microfiller hybrids with mean particle sizes of 160 nm to 0.4 and 0.7 μm. Further 34 wt% of prepolymeric fillers are added. Those fillers consist of a pre-polymerized and re-ground resin composite material and exhibit a mean grain size of approx. 20–50 μm. The microstructure is displayed in Fig. 2. This material has been selected due to the extended filler size distribution which in turn might influence its strength versus surface defect performance.

2.2. Specimen preparation

EMP specimens ($n = 20$) with dimensions 2.5 mm × 2 mm × 25 mm were produced using the Empress system. The pressed bars were in-house manufactured at Ivoclar Corp., Liechtenstein according to the specific recommendations and ISO 6872.

TEC specimens ($n = 15$) with the dimension 2 mm × 2 mm × 25 mm were produced using a metal/glass mold and light-curing on five overlapping spots of 8 mm diameter. The upper and lower side of the bar were cured with a commercial halo-

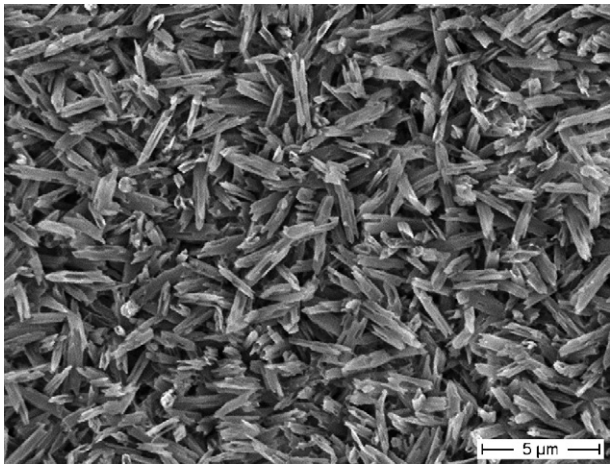

Fig. 1 – Lithiumdisilicate crystallite habit and size in EMP (HF etching for 40 s).