

A STUDY OF CRACKS OCCURRING IN DENTAL MATERIALS

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ABSTRACT:

EVALUATION OF THE MODE OF FAILURE AND CRACK PROPAGATION IN METAL, CERAMIC AND RESIN COMPOSITE DENTAL MATERIALS EXPOSED TO CYCLIC OCCLUSAL LOADING SIMILAR TO MASTICATORY LOADS SHOW THAT IN ORDER TO INCREASE THE SUSTAINABILITY AND LONGEVITY OF DENTAL MATERIALS MUST DEMONSTRATE SUFFICIENT STRENGTH TO DYNAMIC STRESSES. IN THE CASE OF MASTICATORY FORCES WITH HIGH CONTACT TENSIONS, THE CONTACT AREA OF THE SUPERFICIAL LAYERS IS UNDER A STATE OF SPECIAL-COMPLEX VOLTAGE. STRUCTURAL OR MATERIAL VARIATIONS, IMPURITIES, SCRATCHES AND VOIDS CAN DIRECTLY INFLUENCE THE STRUCTURAL INTEGRITY OF THE MATERIAL AND RESULT IN MICRO-CRACKS WHICH PROPAGATE UNDER REPEATED CYCLIC LOADING LEADING TO CATASTROPHIC FAILURE OF THE DENTAL RESTORATION.

KEY WORDS: fatigue strength, implant, plane distortion, plane tension.

1. INTRODUCTION

Internal tensions of appreciable values (400-600) Mpa, negatively influence the durability of metallic and nonmetallic materials. Detailed research of the tension state in the contact area has been undertaken by many researchers. [2], Figure 1.

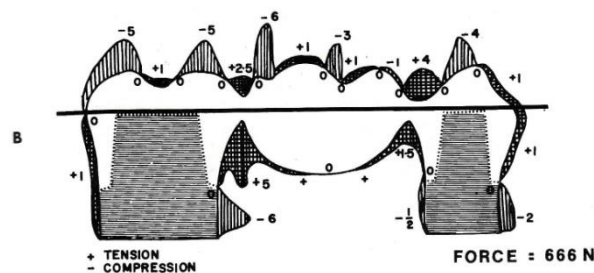
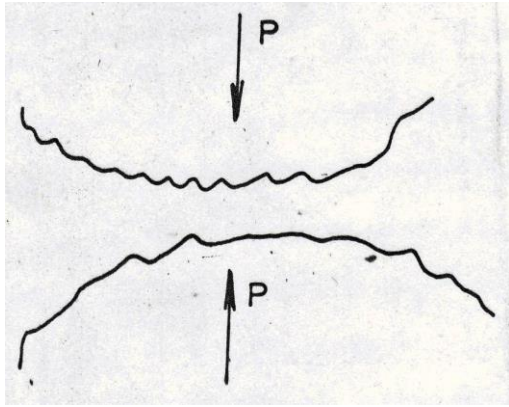


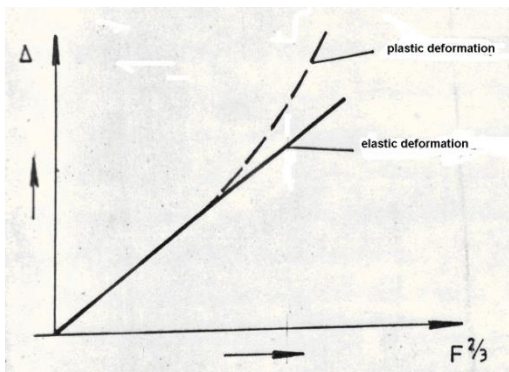
Fig.1 The fringe order or a measure of the magnitude of the stress at the periphery

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Elastic testing at a macro-scale has effects of plastic distortion started at the micro scale, which then transforms to the macro scale, with the increasing number of cyclical stresses, producing cracks that represent the fusing of the breaking phenomenon under fatigue circumstances.

Fig.2 Micro irregularities of the areas of contact



Plastic strains of small value occur even at light loadings due to micro irregularities of the areas of contact (Figure 2). Elastic distortion or Δ proximity between areas of contact varies linearly with the load $F^{2/3}$ (Figure 3).

Fig.3 Graphic representation of the elastic distortion between the areas of contact

2. THEORETICAL AND EXPERIMENTAL ASPECTS

The deformability variation of a material with temperature must be studied in order to choose the field of distortion temperature at which the deformability is maximized to obtain the desired structure and hardness. By controlling the deformability being obtained the required form and properties can be achieved. The material's deformability is expressed by several reports:

$$\varepsilon_l = \frac{l - l_0}{l_0}; \quad \varepsilon_d = \frac{d_0 - d}{d_0}; \quad \psi = \frac{A_0 - A}{A_0}; \quad \varphi = l_a \frac{l}{l_0} \quad (1)$$

where l_0 =the length, d_0 =the diameter and A_0 =the area of the tube's section before distortion and l =the length, d =the diameter and A =the area of the minimum section after the breaking.

On repeated stresses occurring during mastication, the materials are destroyed, sometimes without evidence of remaining strains. The initial crack starts from a defect within the material or processing of the surface. In the case of masticatory loads, a limit of tensions at which fatigue damage does not occur cannot be determined. Materials break at a number of stress cycles, behaving according to curve type 2 from Figure 4.

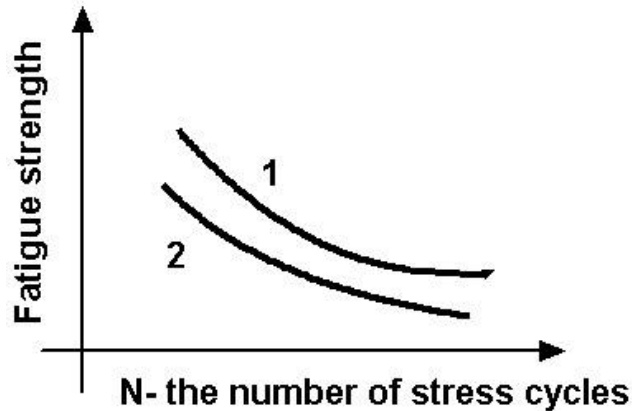


Fig.4 Materials' behavior in case of masticatory loads

Both imperfections and surface defects are weaknesses. In the vicinity of these weaknesses, due to repeated stresses, strong local concentrations of tensions with local modifications occur, resulting in the initiation of the first micro-cracks. Localization of plastic distortion in a small volume of crystals in the cyclical stresses and not its development over most of the crystals in the static stresses radically distinguishes phenomenological variables in time, from the static ones. Generally for metals, the fatigue endurance $\sigma-1$ is contained in the interval (0.40-0.55) σ

Titanium and its alloys are ideal materials for the performance of implants under variable stresses, even under unfavorable environmental conditions. The elements of alloys such as molybdenum, chromium, vanadium and wolfram increase fatigue strength and decrease the sensitivity to tension concentrators. Surface scratches and the number of inclusions may have a negative influence on the structural integrity of the material and may lead to premature destruction of the implant even after a low number of mastication cycles (Figure 5). Chemical and dimensional homogeneity of networks guarantees obtaining high limits of strength to fatigue.



Fig.5 Premature destruction of the implant

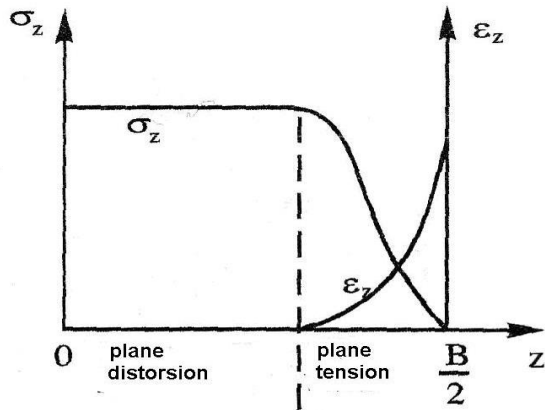


Fig.6 Numerical modeling of the state of tension depending on the thickness of the material

Experimental studies have shown that the initiation of a crack in areas where tangential tensions are maximal coincides with the material's discontinuities. Cracks are propagated towards the surface through the effects of indentations. Generally, the state of tension at the crack's extremity is spatial (Figure 6). Using finite element modeling, it is shown that in areas of the material located towards the surface, the state of tension becomes smooth and distortions occur after the second direction, manifested by a

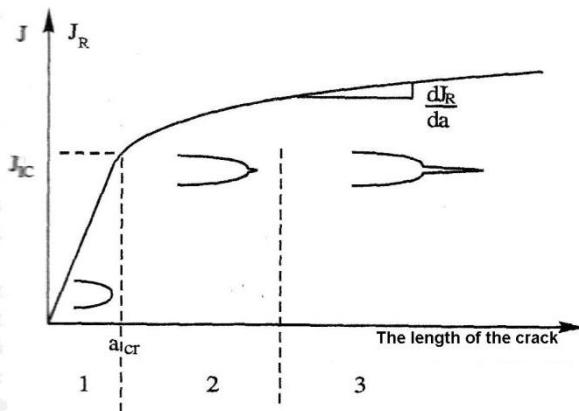


Fig.7 The shape of J curves for ductile materials.

To obtain complete information on the propagation of cracks, examination of the curves of strength to failure Y_r is needed. But the initiation of stable propagation of the crack is practically impossible to be defined with precision, but can be estimated in the same way as the conventional limit of the elastic field. The parameter that provides information on stability of the crack's growth is the tangent of the angle to the curve Y_r to a given point. (Figure 7).

- 1) Rounding phenomena at the crack's extremity;
- 2) Crack's extension-stable propagation;
- 3) Instable propagation of the crack.

Cracks develop starting from interatomic dimensions. The way of occurrence and development of a micro-crack is determined mainly by the crystallographic nature of the material. There are several ways of breakings at the microstructural level:

- fragile transgranular fracture
- fragile intergranular fracture
- fragile shearing fracture
- ductile fracture

3. THE FRACTURE OF CERAMIC MATERIALS

Ceramic materials have a structure based on covalent or ionic bonds. Tensions' values of breaking are lower than the theoretical values, due to defects located at grain limits. Ceramics exhibit a type of intergranular fracture. Impurities in the initial powders with additional substances lead to the formation of segregations at the limit of the grains.

In practice, fractures of ceramic materials sometimes occur because of the static fatigue as consequence of the progressive development of superficial micro-cracks, a phenomenon accelerated by the presence of saliva (in fact, there is an erosion phenomenon under tension).

4. THE FRACTURE OF COMPOSITE MATERIALS

There is not a general valid pattern of fracture with composite material. The aspect and mechanisms that occur are dependent on the internal composition of the composite, the components' nature and fabrication technique. Frequently encountered causes of damage and fracture are residual tensions arising from differences in coefficients of thermal expansion among the constituents¹.

In the case of short fiber composites used as restorative materials, fracture mechanisms are similar to those of metal alloys, through the appearance of the voids and their growth and union in macro-cracks.

5. THE PROPAGATION OF THE CRACKS UNDER FATIGUE

The phenomenon of catastrophic failure caused by variable cyclical stresses that occur for a number of times constitutes the overwhelming cause of failure of materials used in restorative dental procedures². Cycles represented in Figure 8 have approximately the same effect in terms of fatigue strength. In general, during the mastication process random requests such as those in Figure 9 appear. Materials' fatigue studies the changes that occur in mechanical properties of a material subjected to cyclic applications.

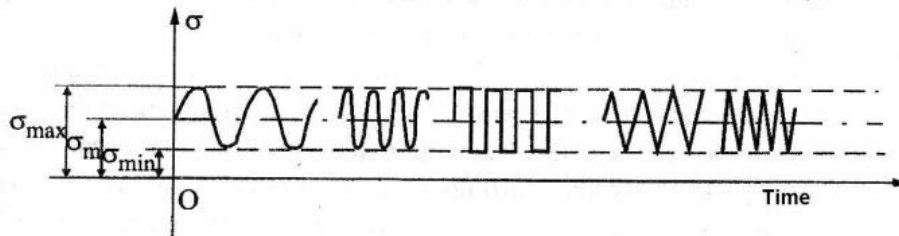


Fig.8 Cycles of fatigue strength

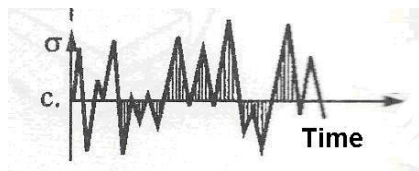


Fig.9 Random stresses occurring during mastication

Fatigue strength depends on the materials composition and structure. A fixed and uniform structure leads to a greater strength than a structure with large granulation size. A surface's state and technical treatments also influence fatigue strength (Figure 10).

¹T. Bolfa, *Strength of Materials* (Brasov: Lux Libris, 2000), 86-89.

²Robert Craig and Floyd Peyton, *Restorative dental materials*(St. Louis: Mosby, 1996), 75-83.

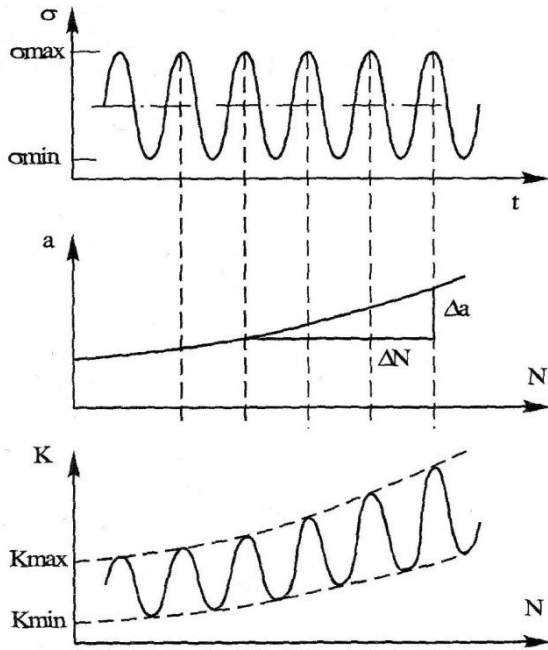


Fig.10 The propagation of a crack's length produces a variation of Kmin size

The increasing length of Δa crack to fatigue will be dependent on:

- the value of maximum factor of intensity of K_{max} tensions
- the value of intensity factor's variation of ΔK tensions
- the value of asymmetry rapport of R cycles

$$\left(R = \frac{\sigma_{min}}{\sigma_{max}} = \frac{K_{min}}{K_{max}} \right)$$

The propagation speed of the crack at fatigue depends on at least two parameters; as a general expression, it may be written:

$$v = \frac{da}{dN} = f(K_{max}, \Delta K) \quad \text{or}$$

$$v = \frac{da}{dN} = f(\Delta K, R) \quad (2)$$

The study of the fatigue phenomena of materials seen in the perspective of exploitation lies in determining the propagation speed of cracks in a certain quality of material. The occurrence of fatigue cracks takes place from the surface through the material phenomena of intrusion-extrusion along slip bands generated by the cyclical application (Figure 11).

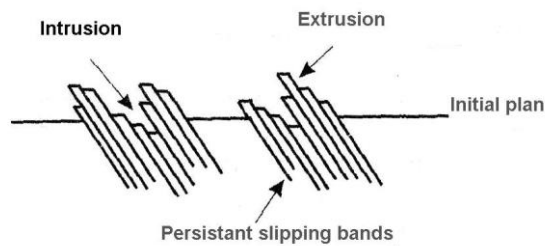


Fig.11 The development of microcracks starting from the material's surface

As observation, it can be concluded that any structure of any material contains micro-cracks after the first cycle of operation. Studying the phenomena of fatigue, the number of cycles N is a reference value, uniquely determined and the crack's length is a questionable value, as the front to propagate the fatigue cracks has an irregular, complex shape. The general shape of a phenomenology model is:

$$\frac{da}{dN} = C(\Delta K)^m \quad (3)$$

where C and m are constants determined experimentally.

Determining the life-span or duration, in the case of cyclical stresses, from the law of expression of cracks' propagation is of practical interest. For the general case of an exponential law:

$$N = \int_{a_i}^{a_f} \frac{da}{C(\Delta K)^m} \quad (4)$$

where a_i is the initial length and a_f represents the final length of the crack (a_f can be considered as critical length and is dependent on the material's ductility).

6. CONCLUSIONS

Resilience has particular importance in the evaluation of orthodontic wires because the amount of work expected from a particular spring in moving a tooth is of interest.

As with other mechanical properties, aging or storage in a simulated oral environment or at elevated temperatures can decrease the fracture toughness. Attempts to correlate fracture toughness with wear resistance have been mixed, and therefore it is not an unequivocal predictor of the wear of restorative materials. Also, numerical analysis techniques have been applied to composites and the tooth-denture base joint to determine energy release rates in the presence of cracks.

A variety of brittle restorative materials, including dental amalgam, cements, ceramic materials, plaster and stone, and some impression materials, is important to dental practice.

The shear strength is the maximum stress that a material can withstand before failure in a shear mode of loading. It is very important in the study of interfaces between two materials, such as a porcelain fused to metal restoration or an implant tissue interface.

A variety of tests are recommended to measure the bond strength between two materials such as porcelains to metal; cements to metal; and polymers, ceramics, resin composites, and adhesives to human enamel and dentin.

When the stress is frequently repeated, the strength of the material may be drastically reduced and ultimately cause failure. Failure under repeated or cyclic loading is therefore dependent on the magnitude of the load and the number of loading repetitions.

The rate of loading is important in many materials, particularly polymers and soft tissues.

Tear strength is a measure of the resistance of a material to tearing forces. Tear strength is an important property of dental polymers used in thin sections, such as flexible impression materials in interproximal areas, maxillofacial materials, and soft liners for dentures. Specimens are usually

crescent shaped and notched. Many materials used in dentistry are not homogeneous solids but consist of two or more essentially insoluble phases. As a further illustration of the factors that effect the properties of a composite, consider the filled polymer resins used in dentistry. For many of these dental composites a random arrangement of the dispersed phase is used, even though a random orientation results in about a sixfold lower strength compared to an oriented dispersed phase.

The property of hardness is of major importance in the comparison of restorative materials. Hardness represents the resistance to permanent surface indentation or penetration. Hardness is therefore a measure of the resistance to plastic deformation.

The importance of friction in dentistry lies in the concept of roughening the surface of a dental implant to reduce motion between the implant and adjacent tissue. It is perceived that a rough surface and resultant decreased motion will provide better osseointegration.

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