ANALELE UNIVERSITĂȚII
"EFTIMIE MURGU" REȘIȚA
ANUL XXII, NR. 1, 2015, ISSN 1453 - 7397

Traian Eugen Bolfa

Fatigue, Wear and Cracking of Dental Materials

Evaluation of the method of failure and crack propagation in dental metals, ceramics and polymer composite materials associated with occlusal activity are associated with contact, twisting and sliding modes. Such loads can result in various combinations of damage due to fatigue and wear. In order to increase sustainability and longevity the dental materials must demonstrate sufficient strength to dynamic stresses. In the case of masticatory forces associated with high contact tensions, the contact area of the superficial layer is under a state of special-complex voltage. Variations in the material or the structure, impurities, scratches and voids can directly influence the structural integrity of the material and result in microscopic cracks. These cracks propagate under repeated cyclic loading leading to dental restoration failure.

Keywords: *cracking, fatigue strength, dental composites, implants*

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.

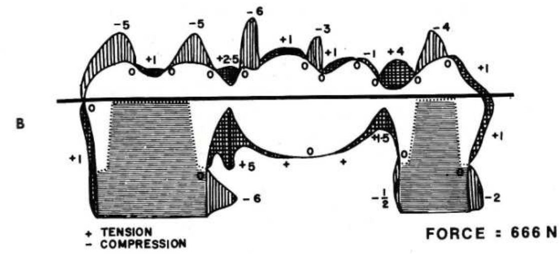
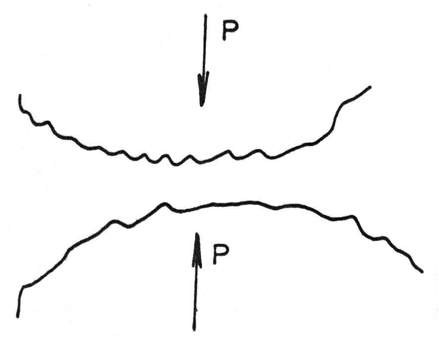
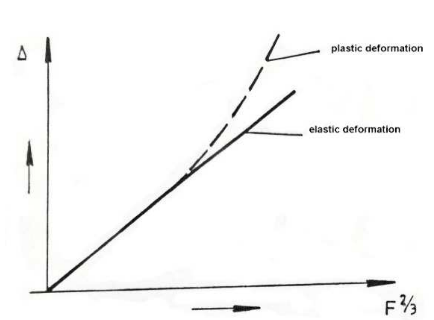


Figure 1. The fringe order or a measure of the magnitude of the stress at the periphery.



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.

Figure 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.

Figure 3. Micro irregularities of the areas of contact.

2. Theoretical and experimental aspects

The principle device used to effectually carry out microscopic analysis consists of the metallographic microscope. The metallographic microscope allows for the enlarged views of a specimen distinguishing an area in greater detail.

After microscopic analysis of the materials surface, images at 100X magnification were obtained. Figure 4.1 presents the Cr-Ni surface of the implant, and Figure 4.2 shows the surface of the Titanium implant. It is evident that the surface of the Cr-Ni implant contains nonmetallic inclusions (oxides). In comparison with Cr-Ni, Ti has a purer structure, characterized by the absence of structural impurities on its surface.

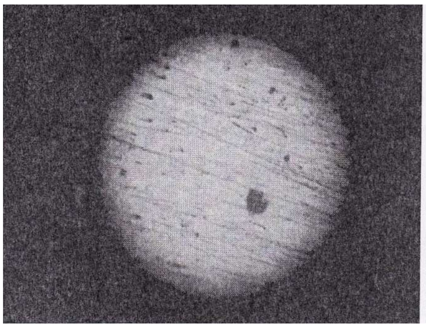
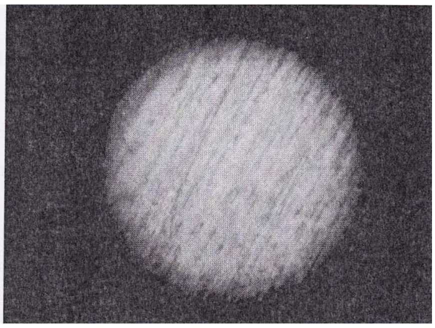
 

Figure 4.1. Cr-Ni implant 100X **Figure 4.2.** Titanium implant 100X

Nonmetallic inclusions influence technological properties (machinability by plastic deformation, and behavior during thermic treatment), and working properties of the metallic materials. The sulfur inclusions are relatively soft and plastic, while the oxide inclusions (SiO_2, Al_2O_3), silicates and spinelles are rough and fragile.

The materials behavior under thermic conditions is influenced by the action of the nonmetallic inclusions on the granulation size. Thereby the finishing of austenite grains is determined by the high dispersion of oxide inclusions (Al_2O_3, V_2O_5, TiO_2) with the role of heterogeneous germs to primary crystallization of austenite. Altogether these inclusions constitute a mechanical barrier with a tendency toward raising the granular austenite during heating, reducing the sensibility of the alloy during overheating.

The mechanical properties are influenced unfavorably, any nonmetallic inclusion constitutes a discontinuity in the metallic mass, which reduces the active section, are local concentrations of tensions, reduce dislocation mobility and have a fracturing effect. Micro fractures reduce mechanical resistance, plasticity, tenacity, fatigue resistance, weld ability and increases corrosion. The properties are influenced by the quantity, chemical composition, form, the size and mode of distribution of the nonmetallic inclusions. Under the action of intercrystalline and intracrystalline coarse inclusions in large proportions the properties worsen pronouncedly. Plastic inclusions maintain a better adherence with the matrix. Rough inclusions such as angular oxide inclusions, favor localized concentrations of tension leading to the appearance of fractures. The rate of speed of the fracture propagation is influenced by the nature of the inclusions. In other words those that are fragile and can crumble in the field of tension form secondary fractures, acceleration the fracture propagation. Rough inclusions that remain intact with the matrix decrease the rate of fracture propagation. The difference between the thermic contraction of the base mass and of the inclusion, as in the case of tempering, can result in fields of tension or structural discontinuities. Otherwise, if the coefficient of contraction is greater than the matrix (MnS, MnSe in alloy), voids appear, if the coefficient is lower (Al_2O_3, Cr_2O_3 in alloy) fields of tension appear on the surface of the inclusions resulting in negative effects especially to fatigue.

In conclusion the resistance to corrosion decreases with the influence of inclusions, since they favor the formation of galvanic microcells composition and elastic distortion. Hence, stainless steels are treated in vacuum.

It is found that in the analyzed implants the alloying elements are distributed unevenly. We notice the presence of a dendritic structure with non-homogenous eutectic. Pieces cast from alloys of NiCr should undergo thermic treatment to homogenize and recrystallize the material. The thermic cycling for homogenization should take place by heating at 1000^{o} C, followed by cooling in air. At a composition of (approximately 64% Ni), a solution is to homogenize the material at approximately 900^{o}C.

3. Materials for dental implants

Dental implants are inert alloplastic materials integrated in the maxilla and/or mandible to replace missing teeth (prosthetic restorations), or to help in the restoration of maxillofacial structures that were deteriorated/lost after trauma, neoplasms or congenital defects [4].

The prosthetic crown is typically attached to the implant by cementation to an abutment which is attached to the implant with an occlusal screw, or the prosthetic crown can be attached directly to the implant with an occlusal screw. A removable prosthesis such as a denture can also be connected to implants through the use of various types of attachments. The implant is the prosthetic element attached to the bone, while the abutment is the element that attaches the prosthesis to the implant, Figure 5. The most widely accepted and successful type of implant to date is the endo-osseous threaded Ti implant (titanium has shown that it can successfully integrate with the osseous mass).

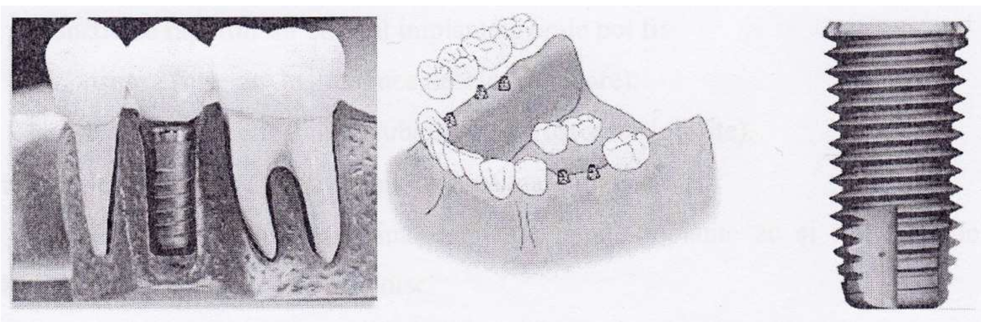


Figure 5. Dental implant and prosthetic restoration on dental implant

Dental implants have been constructed from various materials including different types of metals, metal alloys, ceramics and polymers. Currently in the field of implantology the most popular materials are titanium, titanium alloy, hydroxyapatite, sapphire, bio ceramics and zirconia.

Compression testing of three samples of Cr-Ni, Cr-Co and Gaudent was carried out on a universal testing machine for static load to failure, Figure 6.

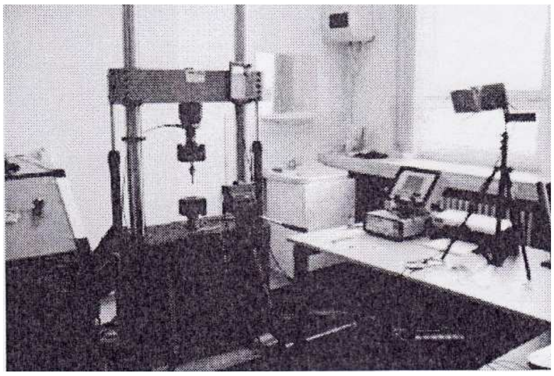


Figure 6. Multipurpose Servo hydraulic Universal Testing Machine, LFV50-HM.

.

Mechanical testing of the materials resistance to compression, gives the possibility of observing the behavior and characteristic parameters through diagrams which express the connection between the applied tensions and specific deformations of the tested materials. At the time of testing with the help of a specific software installed on a personal computer connected to the testing machine, graphic data was obtained showing compressive forces applied in a corresponding specific linear displacement function (Figure 8).

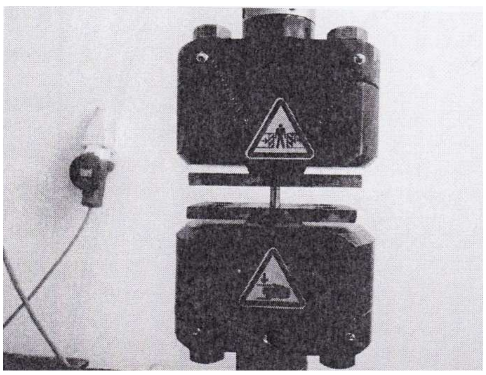


Figure 7. Testing probe prepared for testing

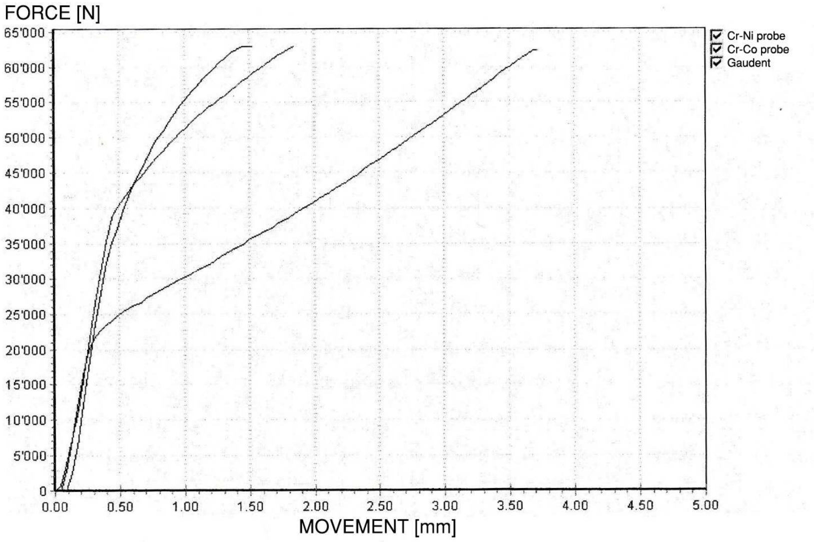


Figure 8. Graph of the compressive forces depending on movement

Up to a certain value of unit force the materials behavior is perfectly elastic, but, after passing this point (0.01%), it enters the plastic domain (flowing of the material). In testing the three materials we observed that the maximum force reaches a value of approximately 63 KN., a value that represents the maximum load of the testing machine.

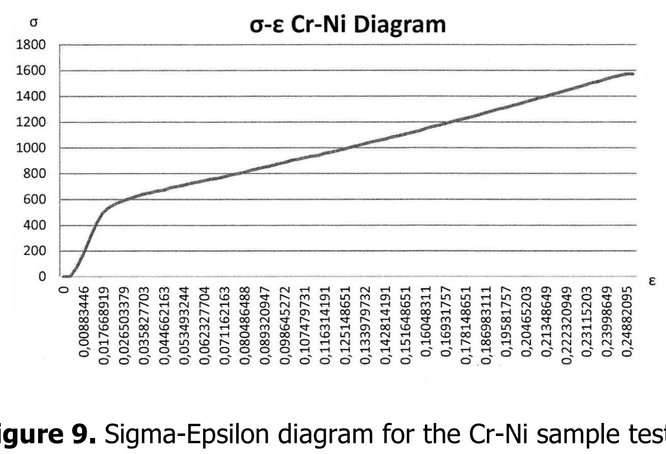


Figure 9. Sigma-Epsilon diagram for the Cr-Ni sample tested

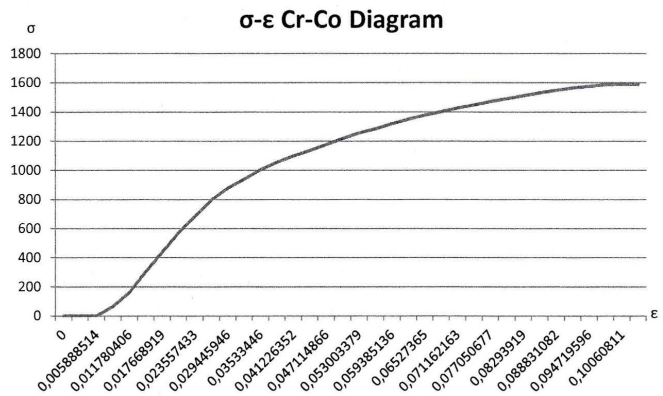


Figure 10. Sigma-Epsilon diagram for the Cr-Co sample tested.

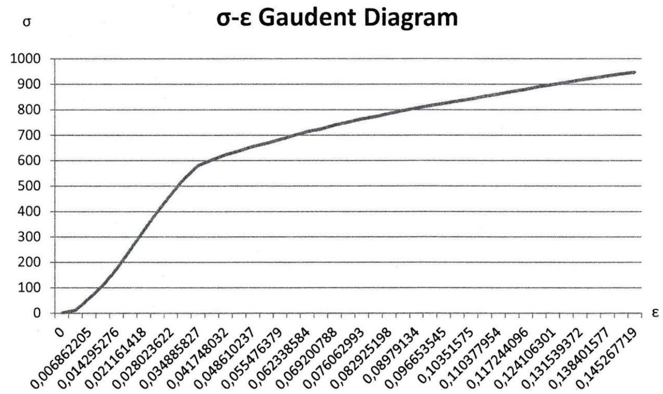


Figure 11. Sigma-Epsilon graph for the Gaudent sample tested.

The results show that the first sample tested, Cr-Ni, shows decreased elastic behavior compared to the other two samples and exhibits greater deformation, Figure 9. Maximum tension (on a scale of 0 N to 1800 N) and specific deformation for each sample were measured. The Cr-Ni sample showed a maximum tension of 1571 N and a specific deformation of 0.251. The Cr-Co sample, showed a maximum tension of 1589 N and a specific deformation of 0.103, Figure 10. The Gaudent sample showed a maximum tension of 946 N and a specific deformation of 0.145, Figure 11.

The maximum force at which the samples were tested was approximately 63,000 N. As a conclusion, the Cr-Ni sample showed an elastic behavior to the loading force to the point of 22,000 N, after which it passed into the plastic domain where the maximum tension is relatively equal to the maximum tension to the Cr-Co sample, but the latter exhibits a much lower specific deformation.

The Gaudent sample showed an elastic behavior to the value of 39,000 N, and exhibited a specific deformation similar to that of the Cr-Co sample, the maximum tension of this sample being equal to 946 N.

4. The fracture toughness of ceramic and composite 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. Intergranular fractures travel along the grain boundaries, rather than through the actual grains. This usually occurs when the phase in the grain boundary is weak and brittle. 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 (erosion phenomenon under tension).

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 constituents [1].

5. Fatigue crack propagation behavior

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 procedures [3]. Cycles represented in Figure 12 have approximately the same effect in terms of fatigue strength. In general, during the mastication process random stresses such appear. Materials' fatigue studies the changes that occur in mechanical properties of a material subjected to cyclic applications.

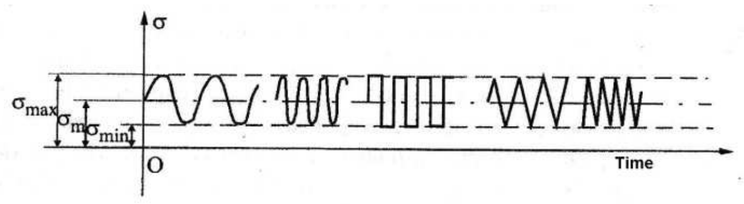


Figure 12. Cycles of fatigue strength.

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 13.

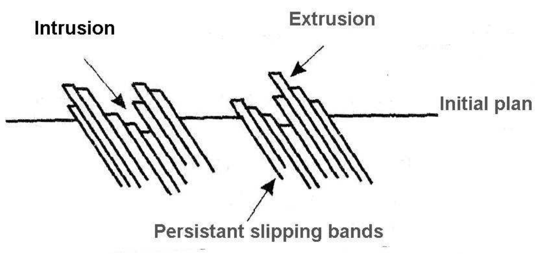


Figure 13. The development of micro-cracks starting from the material´s surface

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:

$$\frac{da}{dN} = C(\Delta K)^m, \quad (1)$$

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:

$$N = \int_{ai}^{af} \frac{da}{C(\Delta K)^m}, \quad (2)$$

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

During mastication a dental restoration is formed where the chewing force acts on the structure of the tooth, the restoration or both and the magnitude of the structure's deformation is determined by the induced stress. Resilience has a particular importance in the evaluation of orthodontic wires because of the amount of work expected from a particular spring to move a tooth.

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 tests are recomended 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.

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.

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, resistance to plastic deformation.

References

[1] Bolfa T.E., Neamtu T., *Research on plastic deformation in conjunction with macro structural parameters*, Research contract number 89/85.

[2] Bolfa T.E., *Strength of Materials*, Brasov, Lux Libris, 2000.

[3] Craig R.G., Peyton F.A., *Restorative dental materials*, St. Louis, Mosby, 1996.

[4] http:/biblioteca.regielive.ro/referate/stomatologie/implante-dentare-304550.html

[5] Dumitriu S., *Fracture Mechanics*, Brasov, Infomarket, 2002.

Address:

- Prof. Dr. Eng. Traian Eugen Bolfa, "Transilvania" University of Brasov, B-dul Eroilor, nr. 29, 500036, Brasov, t.bolfa@unitbv.ro