Fracture Toughness Evaluation of Some Resins Used in Complete Dentures Technology

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Polymer materials for denture bases, with thermal or light polymerization are relatively fragile, being considered brittle materials from the Fracture Mechanics concepts point of view. This paper presents a comparative study on determination of fracture toughness for 2 types of resins used in complete dentures technology: heat-curing resin (Meliodent), and light-curing resin (Eclipse). The tests were performed on a static loading machine, model Zwick/Roell of 5kN. The results obtained by 2 methods differ no more than 10-15%. Both methods showed that Eclipse has a better resistance to fracture than Meliodent.

Keywords: acrylic resins, complete dentures, fracture toughness.

The market introduction of the resin based dental materials has revolutionized the dentistry at 20 mid-century [1]. These resins are polymeric biomaterials, where the polymer is described as a long-chain molecule that consist of a large number of small repeating units, named monomers [2]. They are widely used in dental prosthetics (for complete or partial acrylic dentures, temporary single crowns or temporary fixed dentures) due to good clinical performance and satisfactory handling .Polymers used in dentistry have different structure and composition: the classics are based on polymethyl methacrylate mixed with methyl methacrylate; afterwards appeared macro-molecular compounds type vinyl and epoxy resins, polyurethanes, styrene homo- and copolymers, polyesters, polycarbonates, polyamides, and so on [2].

Complete dentures are used in social health services of the seniors [3]. These prosthetic pieces are frequently damaged, resulting cracks or fractures that need to be repaired. Polymer-based materials for denture bases, with thermal or light polymerization are relatively fragile. Choosing the right material for achieving of complete dentures is very important because it has direct effect on its quality and lifetime [4]. Due to brittle fracture behaviour, mobile prosthetic restorations made of acrylic resins have a limited lifespan in the mouth, the more so as, following laboratory technological steps may remain small defects (holes in the polymer structure) [5]. To this is added the stress exercised by the force of mastication (continuous repeated movement of low amplitude) and the oral environment, which seems to have their own role in the degradation of the prosthesis [6].

Biomaterials diversification allowed the achieving of dentures with high mechanical and biological performances [7]. Being long-term prosthetic pieces, complete dentures need a warranty regarding their mechanical resistance and lifetime. Evaluation of the dentures lifetime and of the materials from which these are realized needs knowledge of fracture mechanics. The basic criterion in fracture mechanics is connected to the crack extent force and the fracture toughness [8,9].

The methods of laboratory testing for fracture toughness determination need to be accessible [10,11]. These generally involve a laborious process of crack inducing, which initiates the fracture [12,13]. But fatigue crack growth cannot be recommended for brittle materials, since it increases the length of existing micro-cracks and other defects, which modify the sample properties [14].

Objectives: The objective of the present paper was to determine the fracture toughness for 2 resins used in complete dentures' technology, using 2 methods and to compare the results.

Experimental part

The materials used for the experiment were light-curing UDMA resin- Eclipse Prosthetic Resin System (Dentsply International Inc. - DeguDent GmbH, Hanau Germany) and heat-curing acrylic resin Meliodent (Heraeus Kulzer, Senden, Germany).

Single-edge-notched beam method (SENB)

The materials have been prepared in accordance with the manufacturer's recommendations in the form of plates with dimensions of 50 x 50 x 2 mm from which were cut

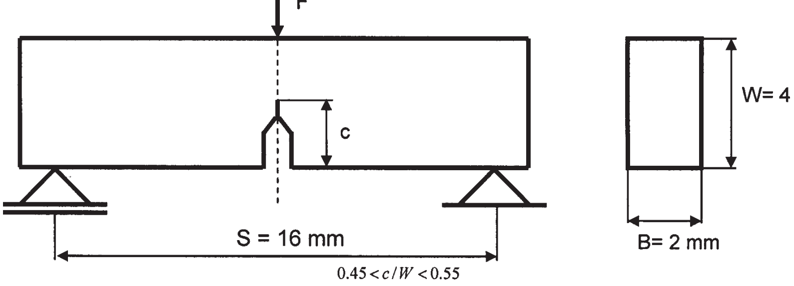

Fig. 1. The SENB specimen configuration

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rectangular beams with dimensions of 4 x 2 x 25 mm (width x thickness x length).

The standard bend specimen is a single edge-notched beam loaded in three-point bending with a support span, S, nominally equal to four times the width, W, S = 4W. The general proportions of this specimen configuration are shown in figure 1. The notches of the specimens were cut with a 0.2 mm thick disc cutter. The notch depth c was nearly half of the specimen's height, W. The bending tests were carried out on a Zwick/Roell ProLine 5 kN testing machine (fig. 2), accordingly with the ASTM D5045 standard [15], the two halves of the broken samples were used for the measurement of the notch depth c. The toughness value was calculated according with the following formula:

$$K_{IC} = \frac{F_c}{B} \cdot \frac{S}{W^{3/2}} \cdot f\left(\frac{c}{W}\right) \qquad (1)$$

$$f\left(\frac{c}{W}\right) = 2.9 \cdot \left(\frac{c}{W}\right)^{1/2} - 4.6 \cdot \left(\frac{c}{W}\right)^{3/2} +$$

$$+ 21.8 \cdot \left(\frac{c}{W}\right)^{5/2} - 37.6 \cdot \left(\frac{c}{W}\right)^{7/2} + 38.7 \cdot \left(\frac{c}{W}\right)^{9/2} \qquad (2)$$

where F_c is the critical load; B the specimen width; S the supporting span; f(c/w) is the stress intensity shape factor.

To validate the test results by this method, the following size criteria must be satisfied:

$$B, c, (W - c) > 2.5 \cdot (K_Q / \sigma_y)^2 \qquad (3)$$

K_Q – the conditional or trial K_{IC} value
σ_y – the yield stress of the material

Fig.2. The three-point bending tests on Zwick/Roell testing machine

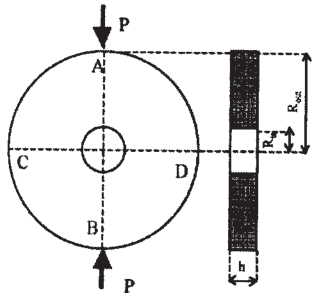
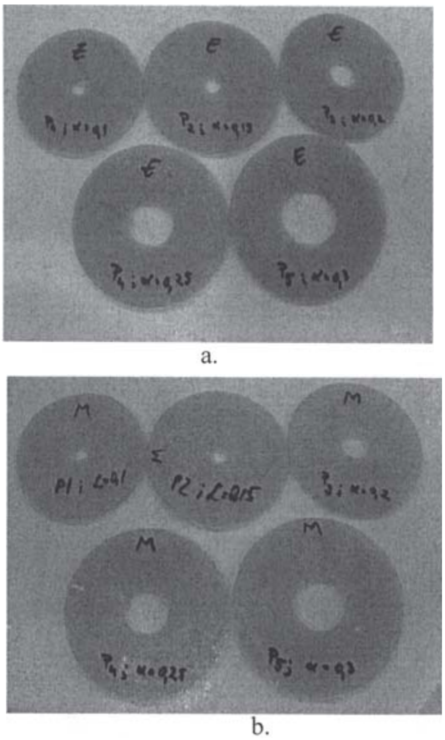


Fig.3. Test sample and loading scheme. R_{in} is the hole radius; R_{out} is the disk radius; h is the disk thickness, and P is the magnitude of applied load.

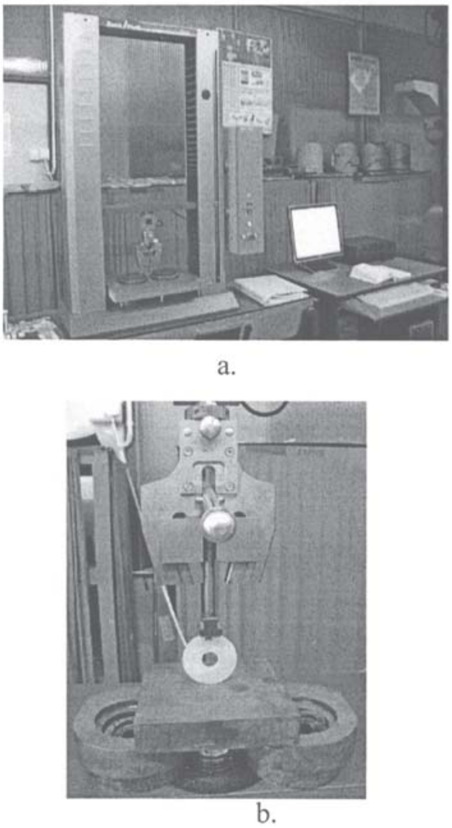
The second test method used samples that have been also prepared according to manufacturer's recommendations, in the shape of a disk with a circular hole in the center (fig.3).



a.

b.

Fig.4. a. Eclipse samples; b. Meliodent samples



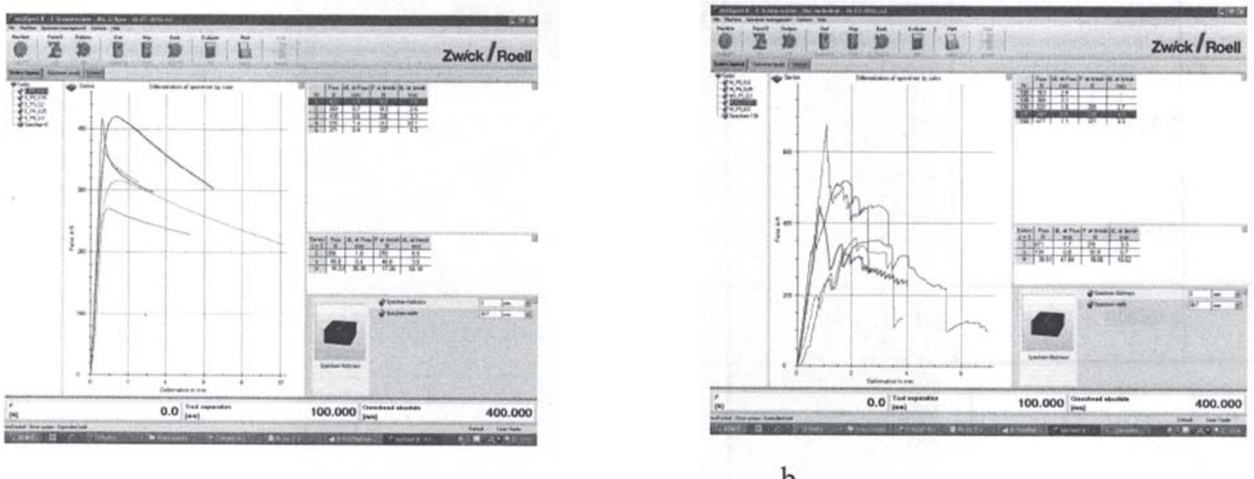
a.

b.

Fig.5. a. Zwick Roel equipment; b. Meliodent sample during compression experiment

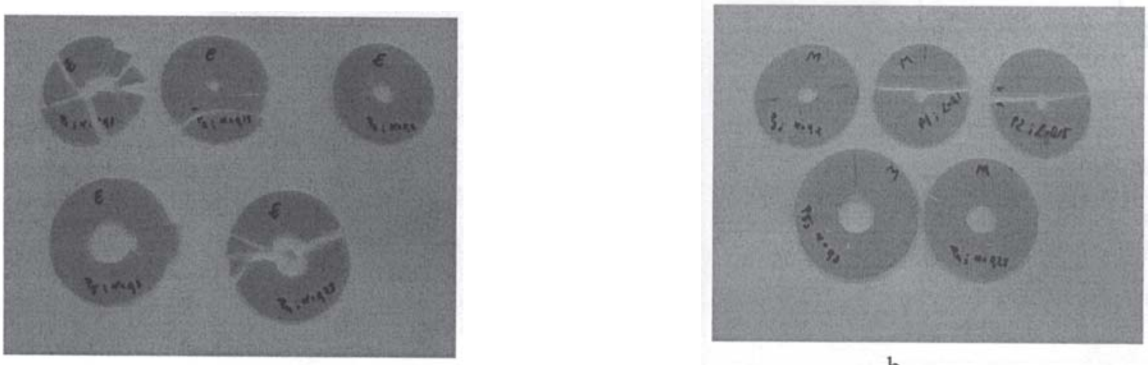
From each material taken into study, one realized 5 samples (fig.2) with the following dimensions: ***sample one***: R_{out}= 42mm, R_{in}= 4.2mm; R_{in}/R_{out}= 0.1, h= 2mm; ***sample 2***: R_{out}= 45mm, R_{in}= 6.75mm; R_{in}/R_{out} = 0.15, h= 2mm; ***sample 3***: R_{out}= 48mm, R_{in}= 9.6mm; R_{in}/R_{out} = 0.2, h= 2mm; ***sample 4***: R_{out}= 50mm, R_{in}= 12.5mm; R_{in}/R_{out} = 0.25, h= 2mm; ***sample 5***: R_{out}= 53mm, R_{in}= 15.9mm; R_{in}/R_{out}= 0.3, h= 2mm.

The compression tests were also performed on a static loading machine (fig.5), model Zwick Roell of 5kN (Zwick



a. b.

Fig.6. Force-displacement diagrams resulted after the compression tests on the tested materials: a. Eclipse, b. Meliodent



a. b.

Fig.7. Aspects of the samples after the compression experiment: a. Eclipse samples; b. Meliodent samples

GmbH & Co. KG, Ulm, Germany), which was connected with a computer (with "testXpert" specific soft). The samples were compressed until breaking.

Each sample was loaded by a pair of point forces P, which acted along the diameter (AB). The distribution of the load across the thickness of the disk was uniform. When the force was applied, the micro-cracks situated in the proximity of the force line (AB), at the edge of the inner hole, started to grow, and, at a certain value of the force gave rise to a macro-crack. Other preexisting cracks within the specimen did not grow. So, the central hole, playing the role of the defect, initiated the fracture.

The fracture toughness was calculated with the formula (1), K_{Ic} depending only on the sample dimensions and critical value of the load.

$$K_{IC} = F^* \cdot \frac{P\sqrt{R_{in}}}{\sqrt{\pi} \cdot R_{out} \cdot h} \qquad (4)$$

where F* is a correction function and depends on the ratio R_{in}/R_{out}.

Results and discussions

The fracture toughness of a material reflects its resistance to fracture and represents the energy required for a crack to propagate through a material to its complete fracture. The fracture toughness of polymers depends on the type of polymer and the reinforcement materials [10]. Fracture toughness of a monomethacrylate- based material is lower than in a dimethacrylate- based material [11]. An increase in fracture toughness can be achieved by adding reinforcement fibres to a polymer to prevent or slow down the crack growth or by adding rubber-like substances [16,17].

It can be seen from the results that the loading rate has an influence on fracture toughness value.

Because the brittle materials are strong in compression and relatively weak in tension, the failure started in the point of inner boundary. In general, the fracture direction was perpendicular on the loading direction. After the tests, one obtained the following values for fracture toughness: K_c= 3.35 MPa√m for Eclipse and K_C= 2.4 MPa√m for Meliodent (fig.6).

Aspects of the samples after the tests are shown in figure 7. As expected, in general the crack developed symmetrically, beginning at the diameter of the inner hole.

In case of SENB method, the experimental values obtained for Kc were: 2.26 MPa√m for Meliodent and 3.18 MPa√m for Eclipse.

Over time several methods have been proposed for determining fracture toughness of materials. It is clear that many methods are not always accurate, since not all of them produce the same result for the same material, or even not give the same ranking for a set of materials. Fracture toughness assessment is rather sensitive to the type of method, configuration, and processing procedures, similar to strength determination [10,14]. The obtained value may be inaccurate, not always consistent with each other, and different methods may offer confusing values and rankings for comparison.

For reliable and reproducible measurements of fracture toughness, recommendations of standardization organizations could be followed, but also other methods can be used as an alternative for evaluating fracture toughness [7,16].

Conclusions

Within the limitations of the present study it is concluded that:

Eclipse has a better resistance to fracture than Meliodent.

By testing of samples without initial cracks, the value of the stress intensity factor- K_{IC} depends only on sample's dimension and on the critical value of the load.

The results obtained through both methods differ no more than 10-15%.

The main advantages of the second method, compared with first one would be: wide area of method applicability-this method can be used for determining K_{IC} for a wide range of materials in different environmental conditions; and no need of time and laboratory work wasting for samples preparation.

Based on the above, the described non standardized testing method is rapid, useful and reliable for determining K_{IC} for a wide class of brittle materials.

Future resin-based materials could reach new standards of quality in the future, by using new trends in materials science, such as the introduction of nanostructures, antimicrobial properties, the ability to respond to stimuli and the ability to promote regeneration / tissue repair [1].

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