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Research Paper

Characterization of Fracture Toughness of Acrylic Denture Base Materials Using Modified Arcan Specimen Test

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Abstract

Acrylic polymers possess diverse applications in the dentistry proteases such as artificial tooth, amendment material of artificial tooth, etc. Nowadays, Poly Methyl Methacrylate (PMMA) is the material which is used in the production of the majority of denture bases. Regarding the clinical process of producing denture bases, the production of micro¬cracks would be inevitable. In the present study, through the production of butterfly Arcan specimens and under the loading conditions in different angles, critical loads of specimens and the pure and mixed mode fracture toughness for the acrylic denture base determined. In this study, the fracture toughness and energy release rate have been calculated through computing the geometric-correction coefficients by utilizing ABAQUS finite element software. Furthermore, the numerical studies have been extended to evaluate the effect of elongation of crack length on the fracture toughness and energy release rate at different loading angles.

Keywords: *Acrylic Denture Base, Arcan test specimen, fracture toughness, mixed-mode.*

1. Introduction

Poly Methyl Methacrylates (PMMA), by adding a small amount of additive, gains properties like natural appearance, color consistency, high coherence, compatibility with the tissue and etc. which are considered the essential features of utilized material in the production of denture base plastics. Considering the existed stresses in the mouth milieu and the presence of micro-cracks, the study of fracture parameters, such as fracture toughness (KI and KII) and energy release rate (GI and GII), are of paramount importance [1].

2. Preparing the specimen and measuring the critical fracture load

For making the specimen, a specific mold was designed and manufacturing. This mold was consisted of four parts made of ply tetra flora etalon (PTEE). Polymer dough was prepared by the proportion of 24.3gr/10mL and after the molding process it was located in a hot bath of water and was hold in the boiling temperature for 45 minute. Using a saw a crack was created in the tip of the twenty-one specimen made by this process with the size of 15mm×0.1mm. The prepared twenty-one Arcan specimen have been fixed in the Arcan fixture at seven different loading angles including 0˚, 15˚, 30˚, 45˚, 60˚, 75˚ and 90˚ and were loaded with displacement rate of 0.5mm/min. The aim of these experiments were achieving the load-displacement contours and finding the critical fracture load (PC) from these contours [2, 3].

In Fig. 1 we can draw a best straight line (AB) to determine the initial compliance, C. C is given by the reciprocal of the slope of line (AB). Then we draw a second line (AB') with a compliance 5% greater than that of line (AB). If the maximum load that the specimen was able to sustain, Pmax, falls within lines (AB) and (AB') use Pmax to calculate KQ .If Pmax falls outside line (AB) and line (AB'), then we can use the intersection of line (AB') and the load curve as PQ. Furthermore, if Pmax/PQ <1.1, we use PQ in the calculation of KQ. However, if Pmax/PQ <1.1, the test is invalid and we should produce specimens with great width or great crack [4]. Values of critical forces were shown in Table 1.

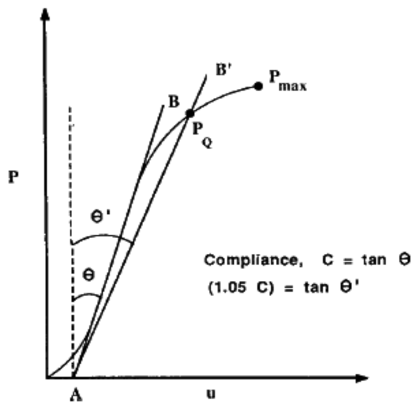

Figure 1: force-displacement curve [4]

Table 1. Values of samples critical forces

α	0	15	30	45	60	75	90
Test 1	683	691	900	1139	1251	1510	2600
Test 2	444	558	451	993	1114	1640	1380
Test 3	437	438	675	1098	1000	1820	2800
Avg.Value(N)	521	562	675/5	1076	1121	1656	2593/33

3. Numerical Analyses

Numerical analyses were carried out using the interaction J-integral method. In order to assess geometrical factors or non-dimensional stress intensity factors fI(a/w) and fII(a/w) for Poly Methyl Methacrylates, the a/w ratio was varied between 0.3 and 0.7 at 0.1 intervals and a Fourth order polynomial was fitted through finite element analysis as Figure 2. Here a/w is the crack length ratio, where a is the crack length and w is the specimen length [2].

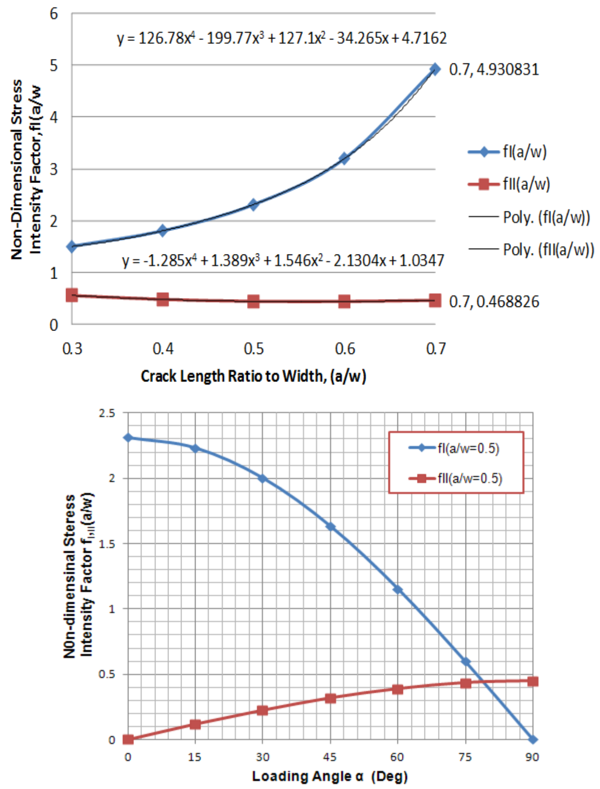

Figure 2: Non-dimensional stress intensity factors A: versus crack length of denture base of plastics and B: versus loading angle

In Figure 2, strain energy release rates GI and GII and the total strain energy release rate obtained by GT = GI + GII are compared for a constant value of the load. It can be seen that for loading angles □≤78 the mode I strain energy release rate is maximum and as loading angle increases, GI decreases and GII increases. For α ≥78 mode-II fracture becomes dominant [3,4].

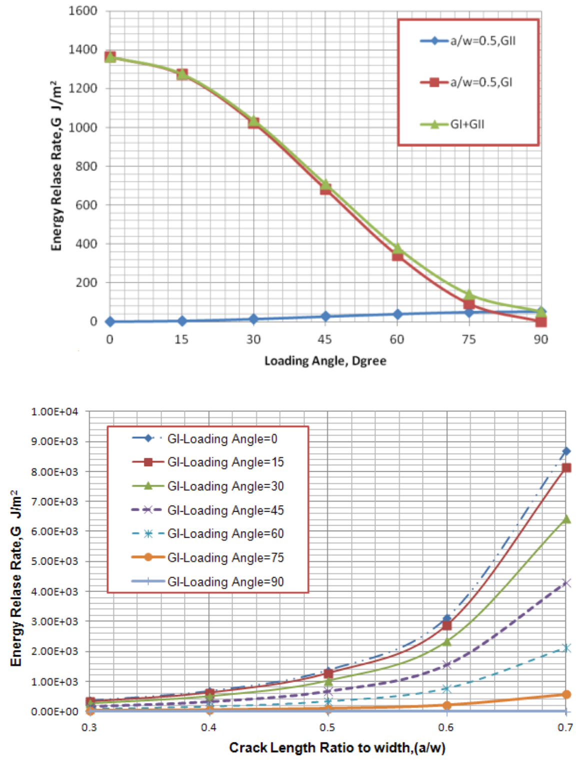

Figure 3 A: GI , GII and GT strain energy release rates versus loading angle, B: changing rate of GI strain energy release with crack length variation in all loading angle

3.1 Calculation of Critical strain energy release rates and critical stress intensity factor

The average values of critical stress intensity factors for denture base of plastics are summarized in Table 2 and the average values of critical strain energy release rates of denture base of plastics are summarized in Table 3.

$$K_{I,II}=\frac{P_c}{wt} f_{I,II}\left(\frac{a}{w}\right), \quad G_{I,II}=\frac{K_{I,II}^{2}}{\bar{E}}, \quad \bar{E}=\frac{E}{1-\vartheta^{2}} \qquad (1)$$

Table 2: Values of critical stress intensity factor

α	0	15	30	45	60	75	90
$K_I(Pa\sqrt{m})$	871632.67	908191.97	977452.65	1273844.81	937128.06	717051.70	5254.29
$K_{II}(Pa\sqrt{m})$	8.293	48477.25	109929.25	284604.93	315836.99	522450.77	*843126.54*
$K_{eff}(Pa\sqrt{m})$	871632.67	909484.85	983614.82	1305251.15	988919.61	887196.67	843142.91

Table 3 Values of critical strain energy release rates

α	0	15	30	45	60	75	90
$G_I(J/m^2)$	354.61432	384.98569	445.94441	*757.39478*	409.90872	293.98838	0.01288
$G_{II}(J/m^2)$	0.000	1.09689	5.74047	37.80716	46.56024	127.4031	*331.79878*
$G_T(J/m^2)$	354.61432	386.08258	451.56488	*795.20194*	456.46896	421.39148	331.81166

4. Microscopic Analyses of surfsce fracture

Studying SEM images (Figures 4 and 5), mode-I and mode-II surface fracture result that both surface fracture occur in a brittle failure process and surface fracture is partly slick. The grooves that insulate height and low locations, shows crack growth path. Attention to produce plastic region and unstable failure in crack tip, rough surface near crack tip expected [5-7].

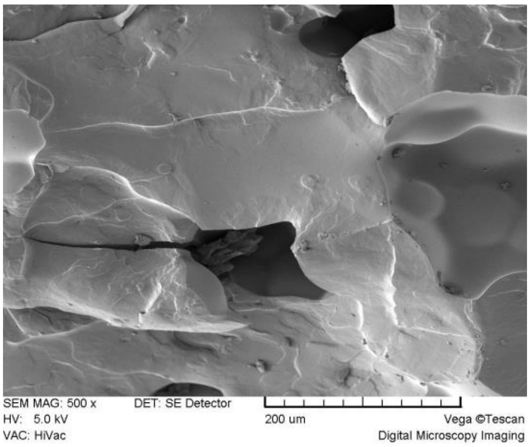

Figure 4 Mode-I surface fracture

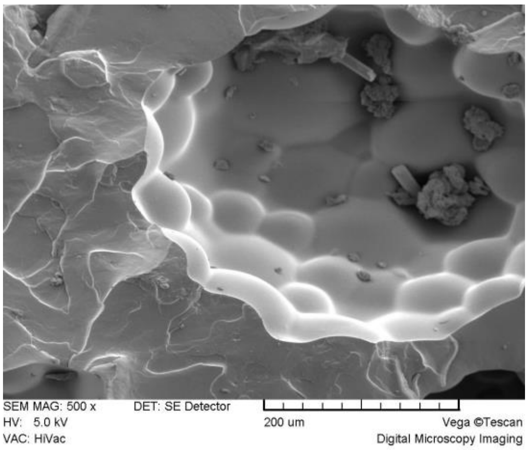

Figure 5 Mode-2 surface fracture

5. Conclusion

Numerical studies have been extended to evaluate the effect of elongation of crack length on the fracture toughness and energy release rate at different loading angles. Results demonstrated that proposed method is efficient and applicable to investigate the materials performance properly with high precision.

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