Ultrasonic Inspection of Composite Resin Restorative Materials

Mirham A. Y. Barakat
National Institute of Standards
P.O. Box: 136 Giza code 12211, Tersa st, Haram, Giza, Egypt
E-mail: mirham75@yahoo.com

Abstract—Restorative materials, such as artificial heart valve, artificial members, artificial lens, etc., are regarded as abnormal materials that are implanted in a normal one. Non-destructive ultrasonic tool can characterize various materials. Therefore ultrasonic technique can be used to characterize restorative materials. Characterizing the implanted restorative materials is very important because these materials can be susceptible to various changes like the creation of inside cracks, surface or deep corrosion, etc. These changes can affect the work efficiency of the implanted restorative material. Ultrasonic pulse-echo technique was used to characterize various discontinuities in dental composite resin samples, which were susceptible to different tensile stress (50, 100, 150, 200, 250, 300 mm/min crosshead speed). The study showed that 100 mm/min crosshead speed is a critical load at which cracks are initiated in the dental restorative material. Otherwise, at 300 mm/min crosshead speed the material was broken, thus it can be said that this dental restorative material can sustain tensile stress below 300 mm/min crosshead speed.

Index Term—Restorative materials, Non-destructive Ultrasonic tool, Cracks, Composite resin, Crosshead speed, Tensile stress.

INTRODUCTION

Composite resin fillings (white fillings) are a mixture of powdered glass and plastic resin, and it can resemble the appearance of the natural tooth. They are cosmetically superior to amalgam fillings, but they are more expensive than amalgam fillings.

Dental composite resins are types of synthetic resins. They are insoluble, aesthetic, insensitive to dehydration and easy to manipulate. Composite resins are most commonly composed of Bis-GMA monomers, a filler material such as silica and in some applications a photoinitiator. Dimethylglyoxime can be added to achieve flow ability. Unique concentrations of each constituent achieve best physical properties.

Unlike amalgam which essentially just fills a hole and requires retention features to hold the filling, composite cavity restorations when used with dentin and enamel bonding techniques restore the tooth back to near its original physical integrity. Nevertheless, amalgam has longer life to failure, but with poor aesthetic qualities [1]. Composite resin is an important industrial product. Therefore, it is regarded as an interested scope for study. Composite resin, as being susceptible to many conditions when implanted, can be a suitable site for various kinds of discontinuities. These discontinuities have a severe influence on the composite resin life time.

The most common discontinuities are the crack-like discontinuities that are present in most composite materials. They can be dispersed all over the prepared specimen or concentrated in one or more site(s) in the specimen. Crack in composite may results from microstructure damage generated by stress, chemical reactions, and thermal aging [2-4].

Non-destructive ultrasonic tool can detect various discontinuities in a material. Especially, when using pulse-echo technique, various discontinuities can be characterized. So it is useful to predict the presence of cracks and the degree of their activation (e.g. exterior stress activation) [5-6]. In addition, the critical crack velocity of the major crack-like discontinuities can be determined.

Both the prediction of the presence of cracks and the degree of their activation, are useful to estimate the life time of the material. Such estimation goes on to state that if the discontinuities will grow or not to a size sufficient to cause failure within a specified interval of time in a specified operational environment [7].

In addition, the critical crack velocity of the major crack-like discontinuities can donate useful information on the life time of a given structure. Because the critical crack velocity is the velocity at which fracture commences and above a certain limit we can estimate if the crack will be stable or unstable (i.e. the crack will be steady or branched) [8].

MATERIALS AND METHODS

1. Specimen preparation

The material of composite resin (CharmFil ® Plus) was bought from DENTKIST INC [Korea] by means of Trading Dynamic Company – Cairo – Egypt. CharmFil ® Plus material is used as restoration of anterior and posterior teeth. In addition, this material has some good characteristics like...
good translucent, excellent handling and less residual monomer.

CharmFit® Plus material (4g) were mixed with CharmBond (A1) and CharmEtch (B1) using a checker apparatus at room temperature. Then, the mixture was poured in a prepared mold (Figure 1). We wait until the mixture become solid, and the piece of composite resin specimen was removed from the mold.

A set of test composite resin specimens were prepared. All specimens had constant dimensions (50*45*4 mm³), and constant single edge notch SEN (3 mm) (Figure 2). SEN were made by thin tip cutter of thickness 1 mm, and they are at the specimens' center.

2. Ultrasonic testing method
By using pulse echo technique, composite resin specimens were studied. The ultrasonic equipment involved the following:
- Oscilloscope (54615B hp) was used to obtain the time traveling through specimen.
- Flaw detector (USIP 20 Krautkramer) was used to display echo.
- Step block, VI and VII blocks was used as reference steel blocks (having known thickness and velocity).
- Longitudinal transducer (12HB Karl Deutsch) having 4 MHz frequency and shear transducer (12HB Karl Deutsch) having 4 MHz frequency.

A conical piece made of Polymethylmethacrylate (PMMA) was used to modify the transducer, Figure 3. This piece assembly the echoes to be concentrated in a point for easily
picking up cracks and also easily follow up the crack track at small points. The conical piece thickness is about 5 mm.

Ultrasonic pulse echoes were recorded from a set of composite resin specimens that had same dimensions (50*45*4 mm³) and same SEN (3mm).

3. Tensile stress process
The prepared composite resin specimens were stressed at different crosshead speeds (50, 100, 150, 200, 250, 300 mm/min) (Zwick apparatus – England) at room temperature [9]. The specimen was put between two grips, and then it was stressed.

RESULTS AND DISCUSSION
1. The location of stress concentration by the characterization of crack-like discontinuities.

Ultrasonic pulse-echo technique was used to localize different crack-like discontinuities, according to the following formula:

\[ d = \frac{v \times t}{2} \]  \hspace{1cm} (1)

Where \( d \) is the position of crack-like discontinuities with respect to the specimens' top surface, \( v \) is the ultrasonic velocity in specimens and \( t \) is the traveling echo time in the specimens.

Table I shows cracks number and position with respect to the specimens' surface after application of different crosshead speeds.

<table>
<thead>
<tr>
<th>Crosshead speed, mm/min</th>
<th>Cracks number</th>
<th>Position (d), mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>No remarkable cracks</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>One main crack</td>
<td>From 23.6 to 24.3</td>
</tr>
<tr>
<td>150</td>
<td>One main crack</td>
<td>From 23.6 to 25.2</td>
</tr>
<tr>
<td>200</td>
<td>Two branched cracks</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; one from 25.2 to 21.7,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>the 2&lt;sup&gt;nd&lt;/sup&gt; one from 25.2 to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>29.5</td>
</tr>
<tr>
<td>250</td>
<td>Three branched cracks</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; one from 25.2 to 21.7,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>the 2&lt;sup&gt;nd&lt;/sup&gt; one from 25.2 to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>29.5, the 3&lt;sup&gt;rd&lt;/sup&gt; from 29.5 to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>32.4</td>
</tr>
<tr>
<td>300</td>
<td>fracture occurred</td>
<td></td>
</tr>
</tbody>
</table>

From Table I, at crosshead speeds of 100 mm/min there are one main crack (from 23.6 to 24.3 mm), which was emerged just after the SEN. This main crack was elongated at 150 mm/min crosshead speed from 24.3 to 25.2. When the crosshead speed was increased to 200 mm/min, the main crack was branched giving rise to other smaller ones that are originated from 25.2 mm (1<sup>st</sup> one from 25.2 to 21.7, the 2<sup>nd</sup> one from 25.2 to 29.5). At crosshead speed of 250 mm/min, another branched minute crack was created at 29.5 mm (from 29.5 to 32.4). Further increase in the crosshead speed to 300 mm/min caused the generation of another minute cracks, which difficult to localize them accurately, they appeared as several noisy echoes in the Flaw detector screen. In addition, at crosshead speed of 300 mm/min, fracture occurred.
Generally, crack-like discontinuities are accompanied by stress concentration around them. Therefore, stress concentration can be known when localizing cracks. In the studied composite resin specimens, stress concentration was around the cracks located at 23.6, 25.2 and 29.5 mm from the composite resin specimens’ surface. In addition, stress concentration could be found around branched minute cracks.

2. The magnitude of stress concentration activation by the characterization of echo amplitude arising from crack-like discontinuities in a given sample, which is susceptible to different crosshead speeds (50, 100, 150, 200, 250, 300 mm/min).

Also, the ultrasonic attenuation coefficient can clarify the effect of crosshead speed on the stress concentration magnitude and also on the crack growth. The attenuation coefficient of ultrasonic is measured by comparing the amplitudes of the pulses (u) that have traveled different acoustic paths (x) in the specimen under study. The attenuation coefficient (\( \alpha \)) was calculated according to the following equation [10]:

\[
\alpha = \left( \frac{1}{(x_2-x_1)} \right) \ln \left( \frac{u_2}{u_1} \right)
\]  

\( (2) \)

Fig. 4. Attenuation coefficient versus crack path (through specimen’s width) for different crosshead speeds.

Figure 4 shows the variation of attenuation along the path of crack when applying different crosshead speeds.

From Figure 4, we can observe the following:

1- There was a decrement in attenuation in the region between 4 to 7 mm of the crack path (through specimen’s width) for about all stressed specimens, which were subjected to different crosshead speeds. This decrement may be due to the presence of several minute cracks generation in the region between 4 to 7 mm of the crack path. Minute cracks caused several gaps, at which there was a big loss in the ultrasonic energy so the attenuation decreased. From the fact that stress concentration is directly proportion to the amount of crack, it can be deduced that the last cited region was the region of high stress concentration due to the lot amount of minute cracks.

2- At 8 mm of the crack path, the attenuation increased. This may be due to the assembly of minute cracks to form a main crack. In another word, the hysteretic region was ended at 8 mm of the crack path.

3- From curves, there is attenuation increment at the region between 8 to 12 mm of the crack path. So, it can be estimated that the main crack formation began in this region, and the stress concentration was lowered.

4- At 300 mm/min crosshead speed, the curve tended to be stable in the region between 12 to 43 mm of the crack path. So, this is the region of fracture. Also this is the region of low stress concentration, due to crack stability and the deficiency in the amount of minute cracks.

5- When the crosshead speed was increased from 100 to 300 mm/min, the attenuation decreased. Stress increment is accompanied with the more formation of cracks. Therefore, the energy loss increased and the attenuation decreased. In return, stress concentration increases with crosshead speeds increment.

3. Measurement of the critical crack velocity of the major crack-like discontinuities in composite resin specimens those were susceptible to different crosshead speeds (50, 100, 150, 200, 250, 300 mm/min).

The importance of detecting the stress concentration is mainly for predicting the probability of the main crack formation. This main crack may leads to fracture. The stress concentration (around minute cracks) could grow at a sufficient degree to help main crack formation. This main crack has critical velocity at which fracture occurs. Therefore, the determination of the critical main crack velocity is important to estimate the life period of a structure.

The stress distribution near the tip of a moving crack was analytically calculated by Yoffe in a continuum model [14]. The calculation showed a bifurcation at a critical velocity \( C_y \).

\[
C_y = 0.6 C_R
\]

(3)

Where: \( C_R \) is the Rayleigh velocity.

The Rayleigh velocity is derived as L. Landau and E. Lifshitz [15].

\[
C_R = 0.9325 C_T
\]

(4)

Where: \( C_T \) is the ultrasonic shear velocity.

By using equations 3 and 4, the critical crack velocity was calculated for the specimens subjected to different crosshead speeds, Figure 6.
From Figure 5, it is clear that the critical crack velocity increased with increasing the crosshead speeds. Thus, it can be said that the crosshead speeds increment promote the molecules motion in the material and enhancing the crack propagation track by voids formation.

In the measured composite resin specimens, we did not see crack bifurcation or branching. So, it can be deduced that the crack was stable. This stability may be due to the crack propagation speed did not reach the calculated critical crack velocity ($C_y$). If the crack propagation speed is below its critical velocity ($C_y$) the crack will be slowed down and prevented from branching. In return, Beyond $C_y$ the stress field becomes more isotropic and the hoop stress develops a maximum in a direction that forms an angle with the direction of propagation which increases with the crack speed [16-17].

CONCLUSION

One of the important conditions for composite resin applications is stress, which has significant influence on the life time of most structures. The life time is a function of structure fracture sustaining. From characterizing the sites of cracks at which fracture may commence or originate, we can predict the life time of most structures.

This study showed that, crosshead speeds affect crack formation. Crack is influenced by crosshead speeds. When crosshead speeds increased the creation of cracks increased. The area, at which there is high amount of cracks, is the area of high stress concentration. The increment of the crosshead speed increased the stress concentration until reaching fracture. Also, crosshead speeds promote the formed main crack; this is shown when the critical crack velocity was increased with crosshead speeds increment.

REFERENCES